



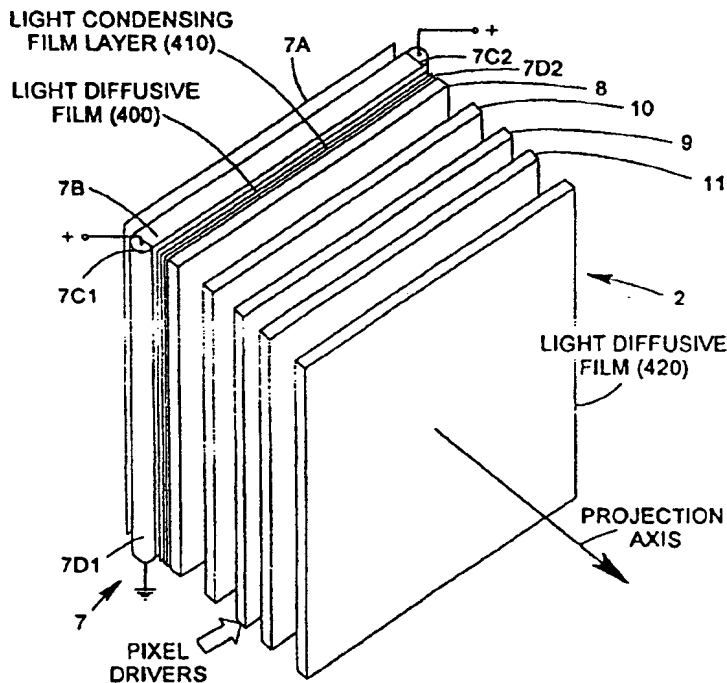
## INTERNATIONAL APPLICATION PUBLISHED UNDER THE PATENT COOPERATION TREATY (PCT)

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(54) Title: HIGH-BRIGHTNESS COLOR LIQUID CRYSTAL DISPLAY PANEL EMPLOYING LIGHT RECYCLING THEREWITHIN

## (57) Abstract

Reflective color filters (10) using layers of cholesteric liquid crystals with two different center wavelengths and bandwidths per layer are stacked in two layers to provide colored light for displays. A two layer stack circularly polarized light of one handedness can be provided (1, 2). A four layer stack unpolarized colored light can be provided. With a broadband polarizing filter overlapping other filters in the stack, a black matrix can be provided by reflecting all colors and transmitting no light in the overlapping areas. When broadband reflective cholesteric liquid crystals are used, two primary colors can be reflected in the same pixel of a display making reflective layers with two reflective portions per layer possible. Color displays (7) having three linear subpixels with three primary colors or with four subpixels of white, blue-green, and red in a pixel with two colors in a top row and two colors on the bottom row are made with two colors per layer in two layer stacks. The pixels in the display are arranged such that multiple adjacent subpixels in a layer, or row in a layer, with the same color makes the color filter easier to manufacture. Displays using these reflective color filters may have a reflective polarizer for viewing the display at wide angles without color distortion.



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HIGH-BRIGHTNESS COLOR LIQUID CRYSTAL DISPLAY PANEL  
EMPLOYING LIGHT RECYCLING THEREWITHIN

BACKGROUND OF INVENTION

Technical Field

The present invention relates to a high-brightness color liquid crystal display (LCD) panel with improved image contrast employing non-absorptive spectral filtering, light recycling among neighboring subpixels and ambient glare reduction, and also to methods and apparatus for manufacturing the same.

Background Art

Without question, there is a great need for flat display panels capable of displaying video imagery in both direct and projection modes of viewing. Examples of equipment requiring such display structures for direct viewing include notebook computers, laptop computers, and palmtop computers, and equipment requiring such display structures for projection viewing include LCD projection panels and LCD image projectors.

In general, prior art color LCD display panels have essentially the same basic construction in that each comprises the following basic components, namely: a backlighting structure for producing a plane of uniform intensity backlighting; an electrically-addressable array of spatial-intensity modulating elements for modulating the spatial intensity of the plane of backlight transmitted therethrough; and an array of color filtering elements in registration with the array of spatial intensity modulating elements, for spectral filtering the intensity modulated light rays transmitted therethrough, to form a color image for either direct or projection viewing. Examples of such prior art LCD panel systems are described in "A Systems Approach to Color Filters for Flat-Panel Displays" by J. Hunninghake, et al, published in SID 94 DIGEST (pages 407-410), incorporated herein by reference.

In color LCD panel design, the goal is to maximize the percentage of light transmitted from the backlighting structure through the color filtering array. However, using prior art design techniques, it has been impossible to achieve this design goal due to significant losses in light transmission caused by the following factors, namely: absorption of

### Background Art

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In color LCD panel design, the goal is to maximize the percentage of light transmitted from the backlighting structure through the color filtering array. However, using prior art design techniques, it has been impossible to achieve this design goal due to significant losses in light transmission caused by the following factors, namely: absorption of light energy due to absorption-type polarizers used in the LCD panels; absorption of light reflected off thin-film transistors (TFTs) and wiring of the pixelated spatial intensity modulation arrays used in the LCD panels; absorption of light by pigments used in the spectral filters of the LCD panels; absorption of light energy by the black-matrix used to spatially separate the subpixel filters in the LCD panel in order to enhance image contrast; and Fresnel losses due to the mismatching of refractive indices between layers within the LCD panels. As a result of such design factors, the light transmission efficiency of prior art color LCD panels is typically no more than 5%. Consequently, up to 95% of the light produced by the backlighting structure is converted into heat across the LCD panel. Thus, it is impossible to produce high brightness images from prior art color LCD panels used in either direct or projection display systems without using ultra-high intensity backlighting sources which require high power supplies, and produce great amounts of heat necessitating cooling measures and the like.

The light transmission efficiency of prior art LCD panels has been severely degraded as a result of the following factors: absorption of light energy due to absorption-type polarizers used in the LCD panels; absorption of light reflected off thin-film transistors (TFTs) and wiring of the pixelated spatial intensity modulation arrays used in the LCD panels; absorption of light by pigments used in the spectral filters of the LCD panels; absorption of light energy by the black-matrix used to spatially separate the subpixel filters in the LCD panel in order to enhance image contrast; and Fresnel losses due to the mismatching of refractive indices between layers within the LCD panels. As a result of such light energy losses, it has been virtually impossible to improve the light transmission efficiency of prior art LCD panels beyond about 5%.

In response to the shortcomings and drawbacks of prior art color LCD panel designs, several alternative approaches have been proposed in order to improve the light transmission efficiency of the panel and thus the brightness of images produced therefrom.

For example, US Patent No. 5,822,029 entitled "Illumination System and Display Device" discloses a LCD panel construction comprising a broad-band CLC reflective polarizer (I) disposed between the backlighting structure (A, B, H and J) and a reflective color filtering structure (C) made from a pair of cholesteric liquid crystal (CLC) film layers, as shown in Figs. 1A and 1B of the accompanying Drawings which are identical to Figs. 5 and 6 in US Patent No. 5,822,029. As shown in Fig. 1A, the reflective color filter structure (C) has a first layer with portions which reflect red-green and blue light while transmitting other colors, and a second layer identical to the first layer but out of alignment therewith so that each region of the spectral filter transmits only one color of light from the light source of the backlighting structure, illustrated in Fig. 1C, while all other colors are reflected back towards the backlighting structure. During operation, the spectral components which are not transmitted through its respective subpixel structure, are reflected back through the broad-band CLC reflective polarizer (I) and recycled within the backlighting structure, after polarization state conversion in order to improve the light transmission efficiency of the LCD panel and thus the output brightness thereof.

In order to recycle light striking the TFT areas and wiring regions associated with each subpixel region on the LCD panel, US Patent 5,822,029 discloses the use of a reflective-type black matrix about the transmission apertures of the subpixels, realized by placing a reflective material (K) and a quarter-wave film on a substrate attached to the layers of CLC reflective material, as shown in Fig. 1B.

In order to improve the viewing angle of the LCD panel, US Patent No. 5,822,029 also discloses in Col. 4, at lines 29-50 thereof, that a collimated light source may be used so

that light emitted by the light source will fall within the angular acceptance bandwidth of the broad-band CLC polarizer (I).

While US Patent No. 5,822,029 discloses an LCD panel construction having the above-described improvements, this prior art LCD panel system nevertheless suffers from a number of significant shortcomings and drawbacks.

For example, the manufacturing of CLC layers having three color regions or sections is quite difficult because of the limited dynamic range in color tuning afforded by the CLC manufacturing techniques disclosed in US Patent No. 5,822,029 and other prior art references.

Adding the reflective-type black matrix pattern to the CLC spectral filter structure increases the complexity of the display system and adds to the overall cost of the display which must be minimized for low-cost consumer product applications.

While recommending the use of light collimation techniques to ensure that the incident upon the spectral filter falls within the angular acceptance bandwidth of its CLC material, US Patent No. 5,822,029 fails to disclose, teach or suggest practical ways of achieving this requirement of CLC material, nor even recognizes in the slightest way the fact that non-collimated light falling on the broad-band CLC reflective polarizer (I) results in significant polarization distortion, as illustrated in Figs. 1D through 1H.

While U.S. Patent No. 5,822,029 discloses the use of CLC-based spectral filters for improved light recycling within a LCD panel, the methods taught therein necessarily result in CLC films having narrow bandwidths which limit their usefulness in creating practical color (i.e. spectral) filter structures for use in LCD panels. While US Patent number 5,822,029 discloses a technique of increasing the bandwidth of the cholesteric liquid crystal material by providing a plurality of different pitches in each portion of the material (e.g. using a thermochromic material during manufacture and varying its temperature while applying ultraviolet light to fix the material), this method is difficult to use in practice and does not produce good results because the bandwidth of the reflective materials is limited to about 80 nm. Applicants have discovered that for good results, a bandwidth of at least 100 nm is required for CLC-based spectral filters.

The CLC-based spectral filters disclosed in US Patent No. 5,822,029 do not have a sufficiently broad spectral bandwidth to reflect all the light needed to make a good quality color reflective filter. Also, since the reflective bandwidth is not large enough in US Patent No. 5,822,029, only one color at a time can be reflected, thereby requiring that prior art CLC-based spectral filters have at least three color reflecting sections per CLC layer, for a two-layer CLC spectral filter structure.

In summary, while it is well known to use CLC-based spectral filters and CLC reflective polarizers within color LCD panel assemblies to improve the brightness of images displayed therefrom, prior art CLC-based LCD panels suffer from several shortcomings and drawbacks relating to: (1) color changes due to viewing angle; (2) controlling the bandwidth of the spectral components to be reflected within the panel for recycling; (3) difficulty in tuning the color-band of spectral components to be transmitted to the viewer for display; (4) difficulty in achieving high contrast between the spectral components in different color bands; (5) difficulty in making CLC-based spectral filter layers which result in spectral filters having high color purity and a broad color gamut; and (6) realizing a reflective-type black matrix which is inexpensive and does not increase the complexity of the system.

Thus, there is a great need in the art for an improved color LCD panel which is capable of producing high brightness color images without the shortcomings and drawbacks of the prior art LCD panel devices.

#### DISCLOSURE OF THE INVENTION

Accordingly, a primary object of the present invention is to provide an improved color LCD panel capable of producing high brightness color images, while avoiding the shortcomings and drawbacks of prior art techniques.

Another object of the present invention is to provide such a color LCD panel, in which the spatial-intensity modulation and spectral (i.e. color) filtering functions associated with each and every subpixel structure of the LCD panel are carried out using systemic light recycling principles which virtually eliminate any and all absorption or dissipation of the spectral energy produced from the backlighting structure during color image production.

Another object of the present invention is to provide such a color LCD panel, in which image contrast enhancement is achieved through the strategic placement of broad-band absorptive-type polarization panels within the LCD panel.

Another object of the present invention is to provide such a color LCD panel, in which glare due to ambient light is reduced through the strategic placement of a broad-band absorptive-type polarization panel within the LCD panel.

Another object of the present invention is to provide such a color LCD panel, in which a single polarization state of light is transmitted from the backlighting structure to the section of the LCD panel along the projection axis thereof, to those structures or subpanels where both spatial intensity and spectral filtering of the transmitted polarized light simultaneously occurs on a subpixel basis in a functionally integrated manner. At each

subpixel location, spectral bands of light which are not transmitted to the display surface during spectral filtering, are reflected without absorption back along the projection axis into the backlighting structure where the polarized light is recycled with light energy being generated therewith. The recycled spectral components are then retransmitted from the backlighting structure into section of the LCD panel where spatial intensity modulation and spectral filtering of the retransmitted polarized light simultaneously reoccurs on a subpixel basis in a functionally integrated manner.

Another object of the present invention is to provide such a color LCD panel, in which the spatial-intensity modulation and spectral filtering functions associated with each and every subpixel structure of the LCD panel are carried out using the polarization/wavelength dependent transmission and reflection properties of CLC-based filters.

Another object of the present invention is to provide such a color LCD panel having a multi-layer construction with multiple optical interfaces, at which non-absorbing broad-band and pass-band (i.e. tuned) polarizing reflective panels are used to carry out systemic light recycling within the LCD panel such that light produced from the backlighting structure is transmitted through the LCD panel with a light transmission efficiency of at least 90%.

Another object of the present invention is to provide a novel LCD panel, in which both non-absorbing broad-band and pass-band (i.e. tuned) polarizer filters are used to avoid absorbing or dissipating any of the spectral energy produced from the backlighting structure during image production in order that high-brightness images can be produced using low-intensity backlighting structures.

Another object of the present invention is to provide such a color LCD panel, in which an array of pass-band CLC polarizing filter elements and an array of electrically-controlled liquid crystal elements are disposed between a pair of broad-band CLC polarizing filter panels used to realize the LCD panel.

Another object of the present invention is to provide such a color LCD panel, in which the spectral components of light produced from the backlighting structure are recycled (i) between the spectral filtering array and the backlighting structure, (ii) within the backlighting structure itself, and (iii) among adjacent subpixels within the LCD panel in order to improve the overall light transmission efficiency of the LCD panel.

Another object of the present invention is to provide such a color LCD panel, in which the array of liquid crystal elements can be realized using an array of electrically-controlled birefringent (ECB) elements which rotate the linear polarization state of the



transmitted light, or invert the polarization state of circularly polarized light being transmitted through the LCD panel.

Another object of the present invention is to provide such a color LCD panel, in which the backlighting structure thereof can be realized using a light guiding panel based on the principle of total internal reflection, a holographic diffuser based on the principle of refractive index matching and first order diffraction, or other suitable edge-lit backlighting structure which follows in general accordance with the physical principles of the present invention.

Another object of the present invention is to increase the brightness of a LCD panel.

Another object of the present invention is to match the color of the cholesteric color filters in a display to the light input color distribution for effective color separation.

Another object of the present invention is to provide a reflective cholesteric liquid crystal (CLC) color filter with only two different color portions in each CLC layer.

Another object of the present invention is to provide a reflective color filter made from cholesteric liquid crystals that transmits red-green and blue light from different pixels with a two layer configuration, where each layer has only two reflection bands.

Another object of the present invention is to provide a reflective-type spectral filter structure for use in display panels, in which the contrast between the colors is significantly improved.

Another object of the present invention is to provide a reflective-type spectral filter structure having a black matrix which is realized by overlapping two layers of reflective color filters.

Another object of the present invention is to provide a reflective-type spectral (i.e. color) filter, wherein each pixel structure contains red, green, blue and transparent subpixels.

Another object of the present invention is to provide an improved display panel that employs cholesteric liquid crystal reflective color filters to transmit desired colors of light having any polarization.

Another object of the present invention is to eliminate the quarter-wave plate in a reflective color filter display.

Another object of the present invention is to provide an easier way of and means for making reflective Cholesteric Liquid Crystal (CLC) color filters.

Another object of the present invention is to provide a reflective-type spectral filter having a patterned color section of increased size achieved by using only two colors per layer without losing the display resolution.

Another object of the present invention is to provide an improved method of making reflective-type spectral filters, in which the boundary effects of pixels are reduced by having larger size patterned color sections per layer.

Another object of the present invention is to provide an improved method of tuning color filters to the desired center wavelength and bandwidth for better color control.

Another object of the present invention is to provide a reflective-type spectral filter which eliminates the need for a separate layer to create a black matrix.

Another object of the present invention is to provide a method of making reflective-type color filters in a cost-reduced manner.

Another object of the present invention is to provide reflective-type color filters having improved performance characteristics.

Another object of the present invention is to provide a reflective-type spectral filter made from layers of broadband reflective cholesteric liquid crystal materials having pitch-gradient characteristics and different central bandwidths.

Another object of the present invention is to provide an improved method of reliably and cost effectively producing broadband reflective cholesteric liquid crystal materials having different central bandwidths.

Another object of the present invention is to provide an improved method of making layers of reflective cholesteric liquid crystal materials with two separate portions having two separate bandwidths and central wavelengths.

Another object of the present invention is provide a reflective-type spectral filter, wherein each side of a layer of cholesteric liquid crystal materials employed therein reflects a different band of wavelengths around a different central wavelength.

Another object of the present invention is to provide a method of making a reflective-type CLC filter, wherein one half of a layer of CLC material is exposed to UV light which is absorbed by attenuation in the cholesteric liquid crystal materials by the time it is one half way through the layer, thus polymerizing one half of the layer.

Another object of the present invention is to provide an improved method of making a reflective-type cholesteric liquid crystal color filter, wherein two different bandwidths of light are reflected in the top portion of the layer, and one bandwidth of light is reflected in the bottom portion of the layer.

Another object of the present invention is to provide an improved method of making a reflective-type spectral filter, wherein there is no need to align and glue together layers of reflective-type materials required by prior art methodologies.

Another object of the present invention is to provide an improved method of making reflective-type CLC filters, wherein several different polymerized states of cholesteric liquid crystal (CLC) materials are stacked together in a single layer of CLC material.

Another object of the present invention is to provide a reflective-spectral filter structure having a quarter-wave plate integrally formed with a reflective-type cholesteric liquid crystal color filter layer.

Another object of the present invention is to provide a reflective-type polarizer integrated with a reflective cholesteric liquid crystal color filter layer.

Another object of the present invention is to provide a method of making a reflective-type CLC filter structure, wherein multiple portions of polymerized cholesteric liquid crystal materials with different properties in each portion are stacked in a single layer of cholesteric liquid crystal material.

Another object of the present invention is to provide novel material recipes for creating reflective-type color filter structure made from the cholesteric liquid crystal material that transmits red-green and blue light components from different subpixels within a two-layer configuration, wherein each such layer has only two reflection bandwidths.

Another object of the present invention is to provide an improved method of making reflective-type color filter structures using a two-layer configuration, wherein each layer has only two reflection bandwidths and contains cholesteric liquid crystals that transmit red-green and blue from different subpixel region.

Another object of the present invention is to provide a device capable of polarizing unpolarized incident light in a reflection mode for a large bandwidth of light over a wide range of incident angles.

Another object of the present invention is to provide a panel capable of polarizing unpolarized incident light in transmission mode for a large bandwidth of light over a wide range of incident angles.

Another object of the present invention is to provide a panel capable of analyzing circularly polarized light in reflection mode for a large bandwidth of light over a wide range of incident angles.

Another object of the present invention is to provide a panel capable of analyzing circularly polarized incident light in a transmission mode for a large bandwidth of light over a wide range of incident angles.

Another object of the present invention is to provide a panel capable of transmitting broadband polarized light without spectral distortions for a large range of angles.

Another object of the present invention is to provide a display device that automatically compensates for color changes occasioned when using reflective-type CLC polarizers.

Another object of the present invention is to provide a display device that automatically compensates for the elliptical distortion of circularly polarized light caused by cholesteric liquid crystals when incident light is transmitted therethrough at large incident angles.

Another object of the present invention is to provide a display device that automatically compensates for the spectral distortion of circularly polarized light caused by cholesteric liquid crystals when incident light is transmitted therethrough at large incident angles.

Another object of the present invention is to provide a display device that automatically compensates for the elliptical distortion of circularly polarized light caused by cholesteric liquid crystals when the light is transmitted therethrough at large incident angles.

Another object of the present invention is to provide a display device that automatically compensates for color distortions associated with polarization distortions of circularly polarized light caused by cholesteric liquid crystals when the light is transmitted therethrough at large incident angles.

Another object of the present invention is to provide a display device that automatically compensates for the severe degradation in polarization behavior of circularly polarized light that occurs when such light is transmitted at large incident angles through CLC-based broadband polarizers employed in the display device.

As a result of the present invention, improved LCD panels can be now made having reflective-type color filters which offer significant advantages over absorptive color filters in that they reflect light for recycling in the system rather than convert the light to unwanted heat as absorptive color filters do. Such a reflective color filter system can enhance the brightness of the display and reach near 100% utilization efficiency. The improved efficiency derives from using reflective-type color filters which reflect light within the system for recycling purposes, rather than absorbing light therewithin as occurs in prior art LCD panels.

By using the reflective color filters of the present invention, the brightness of the LCD display is increased, the cooling systems typically needed to expel wasted heat are eliminated, the power consumption is reduced allowing for smaller batteries and longer life per charge, while the weight and size of the display is reduced and its cost lowered.

In order to make simpler reflective color filters for transmitting red-green, and blue light through subpixels in a display, a novel architecture having two color reflecting portions per layer has been devised. In one illustrative embodiment of the invention, only one film layer is needed because two colors can be reflected by the same film layer when the top part of the layer is tuned to reflect one color of light while the bottom part of the film is tuned to reflect another color of light.

In another embodiment of the present invention, image displays are provided having three primary colors for color images, and arrays of pixels each with three subpixels are provided for transmitting blue, red and green light. With a two layer system, blue and green reflective layers transmit red light, blue reflective layers transmit green light, and green and red reflective layers transmit blue light. Clear subpixels transmit all components of light incident thereon. The clear subpixels can be tuned to reflect ultraviolet and infrared light as applications may require.

In other embodiments of the present invention, if a portion of a broadband layer reflecting blue and green light is paired with a portion of a layer which is clear, then red light is transmitted. When a portion of a broadband layer reflecting green light and red light is paired with a portion of a layer which is clear, then blue light is transmitted. When a portion of a layer which is blue light reflecting is paired with a portion of a layer which is red light reflecting, then green light is transmitted. When the green and red light reflecting a portion in one layer overlaps part of the blue light reflecting portion and part of the blue and green light reflecting portion in the other layer, then a black matrix is formed in the overlapping portion.

The bandwidth of the reflective cholesteric liquid crystals is controllable for wide bandwidths by using a pitch gradient tuning method. Using this method layers of cholesteric liquid crystals reflecting adjacent colors such as both blue and green light and both green and red light are used to precisely tune the colors of light reflected and transmitted by the display. Use of the wider bandwidths allows layers with two color reflecting portions per layer to be constructed instead of three color portions per layer as in the prior art.

When left-handed and right-handed CLC color filters having the same structure are both used, white incident light of any type polarization on the pixels is converted to red-green, and blue light without polarization state distortion. This color filter works for all polarizations of light, e.g. linear, circular, and even unpolarized light. When linearly polarized light is incident on such color filters, which are used in conjunction with conventional twist nematic or super twist nematic in liquid crystal displays, the need for a quarter-wave plate that converts circularly polarized light to linear light is eliminated. This

simplifies the display system, makes fabrication easier, reduces the cost, removes the color chromaticity problem associated with the limited bandwidth of the wave plate, and increases the display contrast ratio by eliminating light losses due to quarter-wave plate bandwidth limitations.

If only a left-handed or only a right-handed circularly polarized light is transmitted from the color filters, then a quarter-wave plate can be used to make the light linearly polarized for use in displays in conjunction with twisted nematic cells and a linear analyzer so as to turn the selectively transmit light to viewers on a subpixel-by-subpixel basis.

The use of a black matrix of one form or another is necessary in all liquid crystal displays (LCD). The novel black matrix structure used in the reflective system of the present invention is formed by using overlapping reflective color filters to reflect all incident light. Therefore no added layers of reflective materials or light absorbing blocking masks are necessary to create the black matrix structure of the present invention.

In accordance with the present invention, the portion of the layer having the same reflective color is enlarged by arranging subpixels with like color portions adjacent to other subpixels, producing the same color, so as to provide larger easier-to-make color portions on each layer. This reduces the cost of manufacture of the LCD of the present invention.

Another object of the present invention is to provide an improved LCD panel wherein a polarization preserving diffuser and a light collimator are arranged about the reflective-type spectral filter structures employed in the LCD panel in order to increase the viewing angle of the LCD panel while keeping the color distortion produced by the spectral filter structure to a minimum level.

These and other objects of the present invention will become apparent hereinafter and in the Claims to Invention.

#### BRIEF DESCRIPTION OF THE DRAWINGS

Other objects, advantages and novel features of the present invention will become apparent from the following Detailed Description Of The Invention when considered in conjunction with the accompanying Drawings, wherein:

Fig. 1A is a schematic representation of the prior art CLC-based LCD panel assembly originally disclosed in Fig. 4 of US Patent No. 5,822,029;

Fig. 1B is a schematic representation of the prior art CLC-based spectral filtering structure originally shown in Fig. 5 of US Patent No. 5,822,029, wherein a quarter-wave

retardation film is applied to a broad-band reflective polarizing pattern applied to a dual-layer CLC spectral filter structure, in order to reflect and recycle light off the TFT, wiring and other non-aperture surface areas of an LCD panel used in conjunction with the prior art illumination system of Fig. 1A;

Fig. 1C is a schematic representation of the intensity distribution of a typical cold-cathode tungsten light source used in the backlighting structures of prior art LCD panels, showing the multiple spectral emission peaks associated with the primary colors blue-green and red;

Fig. 1D is a schematic representation of prior art CLC-based broad band reflective polarizer for use in an LCD panel assembly, as depicted in Fig. 1A, to improve light recycling between the backlighting structure and the spectral filtering structure of the LCD panel assembly;

Fig. 1E is the transmittance characteristics for left-handed and right-handed circularly polarized (LHCP) and (RHCP) light incident upon and transmitted through the CLC-based reflective broadband polarizer employed in the prior art LCD panel assembly of Fig. 1A, at an angle of 0 degrees off the normal thereto;

Fig. 1F is the transmittance characteristics for left-handed and right-handed circularly polarized (LHCP) and (RHCP) light incident upon and transmitted through the CLC-based reflective broadband polarizer employed in the prior art LCD panel assembly of Fig. 1A, at an angle of 30 degrees off the normal thereto;

Fig. 1G is the transmittance characteristics for left-handed and right-handed circularly polarized (LHCP) and (RHCP) light incident upon and transmitted through the CLC-based reflective broadband polarizer employed in the prior art LCD panel assembly of Fig. 1A, at an angle of 50 degrees off the normal thereto;

Fig. 1H is the transmittance characteristics for left-handed and right-handed circularly polarized (LHCP) and (RHCP) light incident upon and transmitted through the CLC-based reflective broadband polarizer employed in the prior art LCD panel assembly of Fig. 1A, at an angle of 70 degrees off the normal thereto;

Fig. 2 is an exploded schematic diagram of the first generalized LCD panel construction of the present invention comprising (i) its backlighting structure realized by a quasi-specular reflector, a light guiding panel, a pair of edge-illuminating light sources, a light condensing film, and broad-band polarizing reflective panel, (ii) its array of spectral filtering elements realized as an array of pass-band polarizing reflective elements; and (iii) its spatial-intensity modulating array realized as an array of electronically-controlled polarization rotating elements, a broad-band polarizing reflective panel and a polarization-

state preserving light diffusive film layer disposed thereon to improve the viewing angle of the system;

Fig. 2A is a perspective, partially broken away view of the LCD panel shown in Fig. 2, showing the electronically-controlled polarization rotating elements associated with a pixel structure thereof;

Fig. 2B is a cross-sectional view of a portion of a first illustrative embodiment of the generalized LCD panel assembly shown in Fig. 2A, taken along lines 2B-2B therein;

Fig. 2B1 is an enlarged view of a subsection of the CLC-based LCD panel assembly shown in Fig. 2B;

Fig. 2B2 is a cross-sectional schematic diagram showing in greater detail the quasi-collimating (i.e. condensing) film layer disposed between the light diffusive layer (for ensuring uniform spatial light intensity across the LCD panel) and the broad-band CLC-based reflective polarizer employed in the LCD panel assembly of Fig. 2;

Fig. 3A1 is a schematic representation of an exploded, cross-sectional view of an exemplary pixel structure within the LCD panel of Fig. 2, wherein the spatial-intensity modulating elements of the LCD panel are realized using circular-type polarization rotating elements, and the pixel driver signals provided thereto are selected to produce "bright" output levels at each of the RGB subpixels of the exemplary pixel structure;

Fig. 3A2 is a schematic representation of an exploded, cross-sectional view of an exemplary pixel structure within the second particular embodiment of the LCD panel of Fig. 2, wherein the spatial-intensity modulating elements of the LCD panel are realized using circular-type polarization rotating elements, and the pixel driver signals provided thereto are selected to produce "dark" output levels at each of the RGB subpixels of the exemplary pixel structure;

Fig. 3B is a schematic representation graphically illustrating ideal reflection characteristics for the broad-band circularly polarizing (LHCP) reflective panel of the LCD panel of Figs. 3A1 and 3A2, indicating how such a broad-band circularly polarizing panel responds to incident illuminating having circular polarization state LHCP;

Fig. 3C is a schematic representation graphically illustrating ideal reflection characteristics for the broad-band circularly polarizing (RHCP) reflective panel of the LCD panel of Figs. 3A1 and 3A2, indicating how such a broad-band circularly polarizing panel responds to incident illuminating having circular polarization state RHCP;

Fig. 3D is a schematic representation graphically illustrating ideal reflection characteristics for the pass-band circularly polarizing (RHCP) reflective filter element associated with each "blue" subpixel of the LCD panel of Figs. 3A1 and 3A2, indicating how



such a non-absorbing spectral filter element responds to incident broad-band illumination having circular polarization state RHCP;

Fig. 3E is a schematic representation graphically illustrating ideal reflection characteristics for the pass-band circularly polarizing (RHCP) reflective filter element associated with each "green" subpixel of the LCD panel of Figs. 3A1 and 3A2, indicating how such a non-absorbing spectral filter element responds to incident broad-band illumination having circular polarization state RHCP;

Fig. 3F is a schematic representation graphically illustrating ideal reflection characteristics for the pass-band circularly polarizing (RHCP) reflective filter element associated with each "red" subpixel of the LCD panel of Figs. 3A1 and 3A2, indicating how such a non-absorbing spectral filter element responds to incident broad-band illumination having circular polarization state RHCP;

Fig. 4 is a cross-sectional schematic diagram of a super-wide-angle CLC-based reflective broadband polarizer employed in the LCD panel assembly of Fig. 2, shown comprising a CLC-based broadband polarizer with multiple compensation layers for the reflected light.

Fig. 4A is the transmittance characteristics for left-handed and right-handed circularly polarized (LHCP) and (RHCP) light incident upon and transmitted through super-wide-angle CLC-based reflective broadband polarizer employed in the LCD panel assembly of Fig. 2, at an angle of 0 degrees off the normal thereto;

Fig. 4B is the transmittance characteristics for left-handed and right-handed circularly polarized (LHCP) and (RHCP) light incident upon and transmitted through super-wide-angle CLC-based reflective broadband polarizer employed in the LCD panel assembly of Fig. 2, at an angle of 30 degrees off the normal thereto;

Fig. 4C is the transmittance characteristics for left-handed and right-handed circularly polarized (LHCP) and (RHCP) light incident upon and transmitted through super-wide-angle CLC-based reflective broadband polarizer employed in the LCD panel assembly of Fig. 2, at an angle of 50 degrees off the normal thereto;

Fig. 4D is the transmittance characteristics for left-handed and right-handed circularly polarized (LHCP) and (RHCP) light incident upon and transmitted through super-wide-angle CLC-based reflective broadband polarizer employed in the LCD panel assembly of Fig. 2, at an angle of 70 degrees off the normal thereto;

Fig. 4E is a schematic representation plotting the extinction ratio of the super-wide-angle CLC-based reflective broadband polarizer used in the LCD panel assembly of Fig. 2, as a function of the film thickness thereof;

Fig. 4F is a schematic representation plotting the color temperature characteristics of the super-wide-angle CLC-based reflective broadband polarizer used in the LCD panel assembly of Fig. 2, as a function of the angle of incidence, for different film thicknesses and  $\Delta n=0.15$ ;

Fig. 4G is a schematic representation plotting the color temperature characteristics of the super-wide-angle CLC-based reflective broadband polarizer used in the LCD panel assembly of Fig. 2, as a function of the angle of incidence, for different film thicknesses and  $\Delta n=0.20$ ;

Fig. 5 is a schematic representation of the a first illustrative embodiment of a two-layer CLC-based spectral filtering structure employed in the LCD panel assembly shown in Fig. 2;

Fig. 5A is an enlarged view of the two-layer CLC-based spectral filtering structure schematically depicted in Fig. 5;

Fig. 5B1 is a schematic cross-sectional diagram of the two-layer CLC-based spectral filtering structure of the first illustrative embodiment of the present invention, wherein each blue subpixel structure therein is realized by a green-band reflecting region in the first CLC layer and a red band reflecting region in the second CLC layer, wherein each green subpixel structure therein is realized by a blue band reflecting region in the first CLC layer and a red band reflecting region in the second CLC layer, wherein each red subpixel structure therein is realized by a blue band reflecting region in the first CLC layer and a green-band reflecting region in the second CLC layer, and wherein a patterned broad-band CLC reflective layer is provided beneath the first CLC layer in order to realize the broad-band inter-subpixel "white" reflective matrix-like pattern between neighboring subpixel regions in order to improve light recycling off the TFT and associated wiring regions surrounding the light transmission aperture of each and every subpixel realized in the liquid crystal (LC) spatial-intensity modulation panel of the LCD panel assembly of Fig. 2;

Fig. 5B2 is a schematic representation of an exemplary broad-band inter-subpixel "white" matrix-like pattern formed about a single pixel structure (each comprising red-green and blue subpixel structures) disposed beneath the lower CLC-filter layer of the CLC-based spectral filtering structure shown in Fig. 5B1;

Fig. 5C is a schematic representation illustrating the spatial layout of an array of pixel structures, as depicted in Figs. 5B1 and 5B2, in the exemplary embodiment of the LCD panel assembly of Fig. 2;

Fig. 6A is a schematic representation graphically illustrating the actual spectral reflection characteristics of a "red-band" reflecting region formed in the second (i.e. top)

patterned CLC layer of the CLC-based spectral filtering structure depicted in Figs. 5 through 5B1, made using CLC film fabrication methods of the present invention disclosed herein, showing that spectral wavelengths residing within the red-band of the electromagnetic spectrum and having a LHCP state are strongly reflected from the layer, while spectral wavelengths residing within the blue and green bands and having a LHCP polarization state are weakly reflected from the layer;

Fig. 6B is a schematic representation graphically illustrating the actual spectral transmission characteristics of a "red-band" reflecting region formed in the second (i.e. top) patterned CLC layer of the CLC-based spectral filtering structure depicted in Figs. 5 through 5B1, made using CLC film fabrication methods of the present invention disclosed herein, showing that spectral wavelengths residing within the blue and green bands of the electromagnetic spectrum and having a LHCP state are strongly transmitted through the layer, while spectral wavelengths residing within the red band and having a LHCP polarization state are weakly transmitted through the layer;

Fig. 6C is a schematic representation graphically illustrating the actual spectral reflection characteristics of a "green-band" reflecting region formed in the second (i.e. top) patterned CLC layer of the CLC-based spectral filtering structure depicted in Figs. 5 through 5B1, made using CLC film fabrication methods of the present invention disclosed herein, showing that spectral wavelengths residing within the green-band of the electromagnetic spectrum and having a LHCP state are strongly reflected from the layer, while spectral wavelengths residing within the blue and red bands and having a LHCP polarization state are weakly reflected from the layer;

Fig. 6D is a schematic representation graphically illustrating the actual spectral transmission characteristics of a "green-band" reflecting region formed in the second (i.e. top) patterned CLC layer of the CLC-based spectral filtering structure depicted in Figs. 5 through 5B1, made using CLC film fabrication methods of the present invention disclosed herein, wherein spectral wavelengths residing within the blue and red bands of the electromagnetic spectrum and having a LHCP state are strongly transmitted through the layer, while spectral wavelengths residing within the green band and having a LHCP polarization state are weakly transmitted through the layer;

Fig. 6E is a schematic representation graphically illustrating the actual spectral reflection characteristics of a "blue-band" reflecting region formed in the second (i.e. top) patterned CLC layer of the CLC-based spectral filtering structure depicted in Figs. 5 through 5B1, made using CLC film fabrication methods of the present invention disclosed herein, showing that spectral wavelengths residing within the blue-band of the electromagnetic

spectrum and having a LHCP state are strongly reflected from the layer, while spectral wavelengths residing within the green and red bands and having a LHCP polarization state are weakly reflected from the layer;

Fig. 6F is a schematic representation graphically illustrating the actual spectral transmission characteristics of a “blue-band” reflecting region formed in the second (i.e. top) patterned CLC layer of the CLC-based spectral filtering structure depicted in Figs. 5 through 5B1, made using CLC film fabrication methods of the present invention disclosed herein, showing that spectral wavelengths residing within the green and red bands of the electromagnetic spectrum and having a LHCP state are strongly transmitted through the layer, while spectral wavelengths residing within the blue band and having a LHCP polarization state are weakly transmitted through the layer;

Fig. 6G is a schematic representation graphically illustrating the actual spectral reflection characteristics of a “blue” subpixel region formed by the composition of the CLC layers in the CLC-based spectral filtering structure depicted in Figs. 5 through 5B1, made using CLC film fabrication methods of the present invention disclosed herein, showing that spectral wavelengths residing within the green and red bands of the electromagnetic spectrum and having a LHCP state are strongly reflected from the subpixel structure, while spectral wavelengths residing within the blue band and having a LHCP polarization state are weakly reflected from the layer (i.e. strongly transmitted therethrough);

Fig. 6H is a schematic representation graphically illustrating the actual spectral reflection characteristics of a “green” subpixel region formed by the composition of the CLC layers in the CLC-based spectral filtering structure depicted in Figs. 5 through 5B1, made using CLC film fabrication methods of the present invention disclosed herein, showing that spectral wavelengths residing within the blue and red bands of the electromagnetic spectrum and having a LHCP state are strongly reflected from the subpixel structure, while spectral wavelengths residing within the green band and having a LHCP polarization state are weakly reflected from the layer (i.e. strongly transmitted therethrough);

Fig. 6I is a schematic representation graphically illustrating the actual spectral reflection characteristics of a “red” subpixel region formed by the composition of the CLC layers in the CLC-based spectral filtering structure depicted in Figs. 5 through 5B1, made using CLC film fabrication methods of the present invention disclosed herein, showing that spectral wavelengths residing within the blue and green bands of the electromagnetic spectrum and having a LHCP state are strongly reflected from the subpixel structure, while spectral wavelengths residing within the red band and having a LHCP polarization state are weakly reflected from the layer (i.e. strongly transmitted therethrough);

Fig. 6J is a schematic representation graphically illustrating the actual spectral reflection characteristics of the "blue-green and red" subpixel regions in the CLC-based spectral filtering structure depicted in Figs. 5 through 5B1, plotted against the spectral emission characteristics of a cold cathode tungsten backlighting structure, employable within the LCD panel assembly of the present invention;

Fig. 7A is a chromaticity diagram for an actual LCD panel assembly constructed in accordance with Figs. 2 through 5C using the CLC-based spectral filtering structure specified by the spectral reflection and transmission characteristics shown in Figs. 6A through 6J, indicating the color coordinates (CC) of a sample pixel structure on the panel at point C, and the color coordinates of the light source employed therein at point B for which the CC of the pixel structure is calculated, for purposes of computing the color purity of the pixel structures in LCD panel assembly;

Fig. 7B is a chromaticity diagram for an actual LCD panel assembly constructed in accordance with Figs. 2 through 5C using the CLC-based spectral filtering structure specified by the spectral reflection and transmission characteristics shown in Figs. 6A through 6J, indicating the computed color gamut of each of the pixel structures in LCD panel assembly, plotted against the color gamut achieved by the pixels of a conventional LCD panel employing an absorptive-type spectral filtering structure;

Fig. 7C is a schematic representation of the extinction ratio characteristics, plotted as a function of wavelength, for each pixel structure in the actual LCD panel assembly constructed in accordance with Figs. 2 through 5C using the CLC-based spectral filtering structure specified by the spectral reflection and transmission characteristics shown in Figs. 6A through 6J;

Fig. 7D1 is a chromaticity diagram for an actual LCD panel assembly constructed in accordance with Figs. 2 through 5C using the CLC-based spectral filtering structure specified by the characteristics shown in Figs. 6A through 6J, and an absorptive-type Jenmar film diffuser mounted on the spatial-intensity modulation panel of the assembly, in order to simulate the expected improvement in angular performance of the LCD panel assembly for spectral components in the blue-band, when the light condensing (i.e. quasi-collimating) film is installed between the light diffusing layer associated with the backlighting panel and the broad-band CLC-based reflective polarizer, and the light diffusing layer is mounted upon the broad-band analyzer of the spatial-intensity modulation panel, as indicated in Figs. 2 through 2B;

Fig. 7D2 is a chromaticity diagram for an actual LCD panel assembly constructed in accordance with Figs. 2 through 5C using the CLC-based spectral filtering structure

specified by the characteristics shown in Figs. 6A through 6J, and an absorptive-type Jenmar film diffuser mounted on the spatial-intensity modulation panel of the assembly, in order to simulate the expected improvement in angular performance of the LCD panel assembly for spectral components in the green-band, when the light condensing (i.e. quasi-collimating) film is installed between the light diffusing layer associated with the backlighting panel and the broad-band CLC-based reflective polarizer, and the light diffusing layer is mounted upon the broad-band analyzer of the spatial-intensity modulation panel, as indicated in Figs. 2 through 2B;

Fig. 7D3 is a chromaticity diagram for an actual LCD panel assembly constructed in accordance with Figs. 2 through 5C using the CLC-based spectral filtering structure specified by the characteristics shown in Figs. 6A through 6J, and an absorptive-type Jenmar film diffuser mounted on the spatial-intensity modulation panel of the assembly, in order to simulate the expected improvement in angular performance of the LCD panel assembly for spectral components in the red-band, when the light condensing (i.e. quasi-collimating) film is installed between the light diffusing layer associated with the backlighting panel and the broad-band CLC-based reflective polarizer, and the light diffusing layer is mounted upon the broad-band analyzer of the spatial-intensity modulation panel, as indicated in Figs. 2 through 2B;

Fig. 8A is a schematic representation illustrating a first method of fabricating the two-layer CLC-based spectral filtering structure shown in Figs. 5 through 5B2;

Fig. 8B is a schematic representation of the final structure produced when using the first method of spectral filter fabrication illustrated in Fig. 8A;

Fig. 8C is a schematic representation illustrating a second alternative method of fabricating the CLC-based spectral filtering structure shown in Figs. 5 through 5B2, wherein the subpixel structures of each pixel structure therein are arranged in a 3x1 array, and the order of the subpixel structures in neighboring pixel structures are periodically reversed to enable manufacturer of CLC layers having double-sized color-band reflection regions;

Fig. 8D1 is a perspective schematic representation of a second illustrative embodiment of the CLC-based spectral filtering structure shown in Fig. 2, wherein the subpixel structures of each pixel structure therein are arranged in a 2x2 array;

Fig. 8D2 is a schematic representation of one pixel structure in the first (i.e. bottom) CLC layer of the CLC-based spectral filtering structure of Fig. 8D1, showing the 2-D spatial layout of the individual subpixel structures contained therein;

Fig. 8D3 is a schematic representation of one pixel structure in the second (i.e. top) CLC layer of the CLC-based spectral filtering structure of Fig. 8D1, showing the 2-D spatial layout of the individual subpixel structures contained therein;

Fig. 8D4 is a schematic representation of light output from the subpixel structures contained in one pixel structure in the CLC-based spectral filtering structure of Fig. 8D1;

Figs. 9A through 9B, taken together, set forth a flow chart illustrating the steps involved when manufacturing the two-layer CLC-based spectral filter of Fig. 5;

Fig. 10 is a schematic representation of a third illustrative embodiment of the CLC-based spectral filtering structure shown in Fig. 2, wherein each red subpixel structure therein is realized by a green-band reflecting region in the first CLC layer and a blue band reflecting region in the second CLC layer, wherein each green subpixel structure therein is realized by a band reflecting region in the first CLC layer and a clear band region in the second CLC layer, wherein each blue subpixel structure therein is realized by a red band reflecting region in the first CLC layer and a green-band reflecting region in the second CLC layer, and a green-blue band reflecting pattern and quarter-wave retardation surface thereover are provided beneath the first CLC layer in order to realize the broad-band inter-subpixel "white" reflective matrix-like pattern between neighboring subpixel regions;

Fig. 10A is a schematic representation of an exemplary broad-band inter-subpixel "white" reflective matrix-like pattern formed about a single pixel structure (each comprising red-green and blue subpixel structures) disposed beneath the lower CLC-filter layer of the CLC-based spectral filtering structure depicted in Fig. 10;

Fig. 11 is a schematic representation of a fourth illustrative embodiment of the CLC-based spectral filtering structure shown in Fig. 2, wherein each red subpixel structure therein is realized by a clear (non-reflecting) region in the first CLC layer and a blue-green band reflecting region in the second CLC layer, wherein each blue subpixel structure therein is realized by a green-red band reflecting region in the first CLC layer and a clear (non-reflecting) region in the second CLC layer, wherein each green subpixel structure therein is realized by a red band reflecting region in the first CLC layer and a blue-band reflecting region in the second CLC layer, and a broad-band reflecting pattern and quarter-wave retardation surface thereover are provided beneath the first CLC layer in order to realize the broad-band inter-subpixel "white" reflective matrix-like pattern between neighboring subpixel regions;

Fig. 11A is a schematic representation of an exemplary broad-band inter-subpixel "white" reflective matrix-like pattern formed about a single pixel structure (each comprising

red-green and blue subpixel structures) disposed beneath the lower CLC-filter layer of the CLC-based spectral filtering structure depicted in Fig. 11;

Fig. 12A is a schematic representation illustrating a first method of fabricating the two-layer CLC-based spectral filtering structure shown in Figs. 11 and 11A;

Fig. 12B is a schematic representation of the final structure produced when using the first method of spectral filter fabricating illustrated in Fig. 12A;

Fig. 13 is a schematic representation of a fifth illustrative embodiment of the CLC-based spectral filtering structure shown in Fig. 2, wherein each red subpixel structure therein is realized by a clear (non-reflecting) region in the first CLC layer and a blue-green band reflecting region in the second CLC layer, wherein each blue subpixel structure therein is realized by a green-red band reflecting region in the first CLC layer and a clear (non-reflecting) region in the second CLC layer, wherein each green subpixel structure therein is realized by a red band reflecting region in the first CLC layer and a blue-band reflecting region in the second CLC layer, and a broad-band inter-subpixel "white" matrix-like pattern is integrally-embodied within the spectral filtering structure, between neighboring subpixel regions, by virtue of (i) the spatially-overlapping green-red band reflecting regions in the first CLC layer and the blue-green band reflecting regions in the second CLC layer, and also (ii) the spatially-overlapping green-red band reflecting regions in the first CLC layer and the blue band reflecting regions in the second CLC layer;

Fig. 13A is a schematic representation of the 2-D spatial layout of an exemplary broad-band inter-subpixel "white" matrix-like pattern integrally-embodied within the CLC-based spectral filtering structure depicted in Fig. 13;

Fig. 14 is a schematic representation illustrating a first method of fabricating the two-layer CLC-based spectral filtering structure shown in Fig. 13;

Fig. 15 is a schematic representation illustrating a second alternative method of fabricating the two-layer CLC-based spectral filtering structure shown in Figs. 13 and 13A, which enables the realization of an integrally-embodied broad-band inter-subpixel "white" matrix-like pattern only among the subpixels of each pixel structure, but not between all neighboring pixel structures within the CLC-based spectral filtering structure;

Fig. 16A is a perspective schematic representation of a sixth illustrative embodiment of the CLC-based spectral filtering structure shown in Fig. 2, wherein the subpixel structures of each pixel structure therein are arranged in a 2x2 array;

Fig. 16B is a schematic representation of one pixel structure in the second (i.e. top) CLC layer of the CLC-based spectral filtering structure of Fig. 16A, showing the 2-D spatial layout of the individual subpixel structures contained therein;



Fig. 16C is a schematic representation of one pixel structure in the first (i.e. bottom) CLC layer of the CLC-based spectral filtering structure of Fig. 16A, showing the 2-D spatial layout of the individual subpixel structures contained therein;

Fig. 16D is a schematic representation of light output from the subpixel structures contained in one pixel structure in the CLC-based spectral filtering structure of Fig. 16A;

Fig. 17A is a perspective schematic representation of a seventh illustrative embodiment of the CLC-based spectral filtering structure shown in Fig. 2, wherein the subpixel structures of each pixel structure therein are arranged in a 2x2 array;

Fig. 17B is a schematic representation of one pixel structure in the second (i.e. top) CLC layer of the CLC-based spectral filtering structure of Fig. 17A, showing the 2-D spatial layout of the individual subpixel structures contained therein;

Fig. 17C is a schematic representation of one pixel structure in the first (i.e. bottom) CLC layer of the CLC-based spectral filtering structure of Fig. 17A, showing the 2-D spatial layout of the individual subpixel structures contained therein;

Fig. 17D is a schematic representation of light output from the subpixel structures contained in one pixel structure in the CLC-based spectral filtering structure of Fig. 17A;

Fig. 18A is a perspective schematic representation of an eighth illustrative embodiment of the CLC-based spectral filtering structure shown in Fig. 2, wherein the subpixel structures of each pixel structure therein are arranged in a 2x2 array;

Fig. 18B is a schematic representation of one pixel structure in the second (i.e. top) CLC layer of the CLC-based spectral filtering structure of Fig. 18A, showing the 2-D spatial layout of the individual subpixel structures contained therein;

Fig. 18C is a schematic representation of one pixel structure in the first (i.e. bottom) CLC layer of the CLC-based spectral filtering structure of Fig. 18A, showing the 2-D spatial layout of the individual subpixel structures contained therein;

Fig. 18D is a schematic representation of light output from the subpixel structures contained in one pixel structure in the CLC-based spectral filtering structure of Fig. 18A;

Fig. 19A is a perspective schematic representation of a ninth illustrative embodiment of the CLC-based spectral filtering structure shown in Fig. 2, wherein the subpixel structures of each pixel structure therein are arranged in a 2x2 array;

Fig. 19B is a schematic representation of one pixel structure in the second (i.e. top) CLC layer of the CLC-based spectral filtering structure of Fig. 19A, showing the 2-D spatial layout of the individual subpixel structures contained therein;

Fig. 19C is a schematic representation of one pixel structure in the first (i.e. bottom) CLC layer of the CLC-based spectral filtering structure of Fig. 19A, showing the 2-D spatial layout of the individual subpixel structures contained therein;

Fig. 19D is a schematic representation of light output from the subpixel structures contained in one pixel structure in the CLC-based spectral filtering structure of Fig. 19A;

Fig. 20A is a perspective schematic representation of a tenth illustrative embodiment of the CLC-based spectral filtering structure shown in Fig. 2, wherein the subpixel structures of each pixel structure therein are arranged in a 2x2 array;

Fig. 20B is a schematic representation of one pixel structure in the second (i.e. top) CLC layer of the CLC-based spectral filtering structure of Fig. 20A, showing the 2-D spatial layout of the individual subpixel structures contained therein;

Fig. 20C is a schematic representation of one pixel structure in the first (i.e. bottom) CLC layer of the CLC-based spectral filtering structure of Fig. 20A, showing the 2-D spatial layout of the individual subpixel structures contained therein;

Fig. 20D is a schematic representation of light output from the subpixel structures contained in one pixel structure in the CLC-based spectral filtering structure of Fig. 20A;

Fig. 21A is a perspective schematic representation of a eleventh illustrative embodiment of the CLC-based spectral filtering structure shown in Fig. 2, wherein the subpixel structures of each pixel structure therein are arranged in a 2x2 array;

Fig. 21B is a schematic representation of one pixel structure in the second (i.e. top) CLC layer of the CLC-based spectral filtering structure of Fig. 21A, showing the 2-D spatial layout of the individual subpixel structures contained therein;

Fig. 21C is a schematic representation of one pixel structure in the first (i.e. bottom) CLC layer of the CLC-based spectral filtering structure of Fig. 21A, showing the 2-D spatial layout of the individual subpixel structures contained therein;

Fig. 21D is a schematic representation of light output from the subpixel structures contained in one pixel structure in the CLC-based spectral filtering structure of Fig. 21A;

Fig. 22A is a perspective schematic representation of a twelfth illustrative embodiment of the CLC-based spectral filtering structure shown in Fig. 2, wherein the subpixel structures of each pixel structure therein are arranged in a 2x2 array;

Fig. 22B is a schematic representation of one pixel structure in the second (i.e. top) CLC layer of the CLC-based spectral filtering structure of Fig. 22A, showing the 2-D spatial layout of the individual subpixel structures contained therein;

Fig. 22C is a schematic representation of one pixel structure in the first (i.e. bottom) CLC layer of the CLC-based spectral filtering structure of Fig. 22A, showing the 2-D spatial layout of the individual subpixel structures contained therein;

Fig. 22D is a schematic representation of light output from the subpixel structures contained in one pixel structure in the CLC-based spectral filtering structure of Fig. 22A;

Fig. 23A is a perspective schematic representation of a thirteenth illustrative embodiment of the CLC-based spectral filtering structure shown in Fig. 2, wherein the subpixel structures of each pixel structure therein are arranged in a 2x2 array;

Fig. 23B is a schematic representation of one pixel structure in the second (i.e. top) CLC layer of the CLC-based spectral filtering structure of Fig. 23A, showing the 2-D spatial layout of the individual subpixel structures contained therein;

Fig. 23C is a schematic representation of one pixel structure in the first (i.e. bottom) CLC layer of the CLC-based spectral filtering structure of Fig. 23A, showing the 2-D spatial layout of the individual subpixel structures contained therein;

Fig. 23D is a schematic representation of light output from the subpixel structures contained in one pixel structure in the CLC-based spectral filtering structure of Fig. 23A;

Fig. 24A is a perspective schematic representation of a fourteenth illustrative embodiment of the CLC-based spectral filtering structure shown in Fig. 2, wherein the subpixel structures of each pixel structure therein are arranged in a 2x2 array;

Fig. 24B is a schematic representation of one pixel structure in the second (i.e. top) CLC layer of the CLC-based spectral filtering structure of Fig. 24A, showing the 2-D spatial layout of the individual subpixel structures contained therein;

Fig. 24C is a schematic representation of one pixel structure in the first (i.e. bottom) CLC layer of the CLC-based spectral filtering structure of Fig. 24A, showing the 2-D spatial layout of the individual subpixel structures contained therein;

Fig. 24D is a schematic representation of light output from the subpixel structures contained in one pixel structure in the CLC-based spectral filtering structure of Fig. 24A;

Fig. 25 is a fifteenth illustrative embodiment of the CLC-based spectral filtering structure shown in Fig. 2 which is polarization independent, and wherein each blue subpixel structure therein is realized by a green-band RHCP reflecting region in the first CLC layer, a red-band RHCP reflecting region in the second CLC layer, a green-band LHCP reflecting region in the third CLC layer, and a red-band LHCP reflecting region in the fourth CLC layer, wherein each green subpixel structure therein is realized by a blue-band RHCP reflecting region in the first CLC layer, a red-band RHCP reflecting region in the second CLC layer, a blue-band LHCP reflecting region in the third CLC layer and a red-band LHCP

reflecting region in the fourth CLC layer, and wherein each red subpixel structure therein is realized by a blue-band RHCP reflecting region in the first CLC layer, a green-band RHCP reflecting region in the second CLC layer, a blue-band LHCP reflecting region in the third CLC layer, and a green-band LHCP reflecting region in the fourth CLC layer;

Fig. 26 is a sixteenth illustrative embodiment of the CLC-based spectral filtering structure shown in Fig. 2 which is polarization independent, and wherein each red subpixel structure therein is realized by a clear (i.e. non-reflecting) region in the first CLC layer, a blue-green-band RHCP reflecting region in the second CLC layer, a clear non-reflecting region in the third CLC layer, and a blue-green band LHCP reflecting region in the fourth CLC layer, wherein each blue subpixel structure therein is realized by a green-red band RHCP reflecting region in the first CLC layer, a clear non-reflecting region in the second CLC layer, a green-red band LHCP reflecting region in the third CLC layer, and a clear non-reflecting region in the fourth CLC layer, and wherein each green subpixel structure therein is realized by a red-band RHCP reflecting region in the first CLC layer, a blue-band RHCP reflecting region in the second CLC layer, a red-band LHCP reflecting region in the third CLC layer, and a blue-band LHCP reflecting region in the fourth CLC layer, and wherein a inter-subpixel "white" reflective matrix-like pattern is integrally-embodied within the spectral filtering structure, between neighboring red and blue subpixel regions by virtue of (i) the spatially-overlapping green-red band RHCP reflecting regions in the first CLC layer and the blue-green band RHCP reflecting regions in the second CLC layer, (ii) the spatially-overlapping blue-green band RHCP reflecting regions in the second CLC layer and the green-red band LHCP reflecting regions in the third CLC layer, and (iii) the spatially-overlapping green-red band LHCP reflecting regions in the third CLC layer and the blue-green band LHCP reflecting regions in the fourth CLC layer, between the red and blue subpixel regions, and between neighboring blue and green subpixel regions by virtue of (i) the spatially-overlapping green-red band RHCP reflecting regions in the first CLC layer and the blue band RHCP reflecting regions in the second CLC layer, (ii) the spatially-overlapping blue band RHCP reflecting regions in the second CLC layer and the green-red band LHCP reflecting regions in the third CLC layer, and (iii) the spatially-overlapping green-red LHCP band reflecting regions in the third CLC layer and the blue band LHCP reflecting regions in the fourth CLC layer;

Fig. 27 is a seventeenth illustrative embodiment of the CLC-based spectral filtering structure shown in Fig. 2 which is polarization independent, and wherein each blue subpixel structure therein is realized by a red-band RHCP reflecting region in the first CLC layer, a green-band RHCP reflecting region in the second CLC layer, a red-band LHCP reflecting

region in the third CLC layer, and a green-band LHCP reflecting region in the fourth CLC layer, wherein each red subpixel structure therein is realized by a blue-band RHCP reflecting region in the first CLC layer, a green-band RHCP reflecting region in the second CLC layer, a blue-band LHCP reflecting region in the third CLC layer and a green-band LHCP reflecting region in the fourth CLC layer, and wherein each green subpixel structure therein is realized by a blue-band RHCP reflecting region in the first CLC layer, a red-band RHCP reflecting region in the second CLC layer, a blue-band LHCP reflecting region in the third CLC layer, and a red-band LHCP reflecting region in the fourth CLC layer;

Fig. 28 is an eighteenth illustrative embodiment of the CLC-based spectral filtering structure shown in Fig. 2 which is polarization independent, and wherein each blue subpixel structure therein is realized by a green-band RHCP reflecting region in the first CLC layer, a red-band RHCP reflecting region in the second CLC layer, a green-band LHCP reflecting region in the third CLC layer, and a red-band LHCP reflecting region in the fourth CLC layer, wherein each green subpixel structure therein is realized by a green-band RHCP reflecting region in the first CLC layer, a red-band RHCP reflecting region in the second CLC layer, a blue-band LHCP reflecting region in the third CLC layer and a red-band LHCP reflecting region in the fourth CLC layer, and wherein each red subpixel structure therein is realized by a blue-band RHCP reflecting region in the first CLC layer, a green-band RHCP reflecting region in the second CLC layer, a blue-band LHCP reflecting region in the third CLC layer, and a green-band LHCP reflecting region in the fourth CLC layer;

Fig. 29 is a cross-sectional view of a portion of a second illustrative embodiment of the generalized LCD panel assembly shown in Fig. 2;

Fig. 29A is a schematic representation of a first illustrative embodiment of a single-layer CLC-based spectral filtering structure which can be employed in the LCD panel assembly shown in Fig. 2;

Fig. 30A1 is a schematic representation of an exploded, cross-sectional view of an exemplary pixel structure within the LCD panel of Fig. 29, wherein the spatial-intensity modulating elements of the LCD panel are realized using linear-type polarization rotating elements, and the pixel driver signals provided thereto are selected to produce "bright" output levels at each of the RGB subpixels of the exemplary pixel structure;

Fig. 30A2 is a schematic representation of an exploded, cross-sectional view of an exemplary pixel structure within the second particular embodiment of the generalized LCD panel of Fig. 2, wherein the spatial-intensity modulating elements of the LCD panel are realized using linear-type polarization rotating elements, and the pixel driver signals

provided thereto are selected to produce "dark" output levels at each of the RGB subpixels of the exemplary pixel structure;

Fig. 30B is a schematic representation graphically illustrating ideal reflection characteristics for the broad-band linearly polarizing (LHP1) reflective panel of the LCD panel of Figs. 30A1 and 30A2, indicating how such a broad-band linearly polarizing panel responds to incident illuminating having linear polarization state LP1;

Fig. 30C is a schematic representation graphically illustrating ideal reflection characteristics for the broad-band linearly polarizing (LP2) reflective panel of the LCD panel of Figs. 30A1 and 30A2, indicating how such a broad-band linearly polarizing panel responds to incident illuminating having linear polarization state LP2;

Fig. 30D is a schematic representation graphically illustrating ideal reflection characteristics for the pass-band linearly polarizing (LP2) reflective filter element associated with each "blue" subpixel of the LCD panel of Figs. 30A1 and 30A2, indicating how such a non-absorbing spectral filter element responds to incident broad-band illumination having linear polarization state LP2;

Fig. 30E is a schematic representation graphically illustrating ideal reflection characteristics for the pass-band linearly polarizing (LP2) reflective filter element associated with each "green" subpixel of the LCD panel of Figs. 30A1 and 30A2, indicating how such a non-absorbing spectral filter element responds to incident broad-band illumination having linear polarization state LP2;

Fig. 30F is a schematic representation graphically illustrating ideal reflection characteristics for the pass-band linearly polarizing (LP2) reflective filter element associated with each "red" subpixel of the LCD panel of Figs. 30A1 and 30A2, indicating how such a non-absorbing spectral filter element responds to incident broad-band illumination having linear polarization state LP2;

Fig. 31 is an exploded schematic diagram of the second generalized LCD panel construction of the present invention comprising (i) its backlighting structure realized by a quasi-specular reflector, a light guiding panel, a pair of edge-illuminating light sources, a light condensing film, and broad-band polarizing reflective panel, (ii) its spatial-intensity modulating array realized as an array of electronically-controlled polarization rotating elements and a broad-band polarizing reflective panel, and (iii) its array of spectral filtering elements realized as an array of pass-band polarizing reflective elements and a polarization-state preserving light diffusive film layer disposed thereon to improve the viewing angle of the system;

Fig. 31A is a perspective, partially broken away view of the LCD panel shown in Fig. 29, showing the electronically-controlled polarization rotating elements associated with a pixel structure thereof;

Fig. 31A1 is a schematic representation of an exploded, partially cut-away cross-sectional view of a first illustrative embodiment the second generalized CLC-based LCD panel assembly shown in Fig. 31, wherein the spatial-intensity modulating panel is disposed between the backlighting structure and the spectral filtering structure of the system and the spatial-intensity modulating elements employed therein are realized using circularly-type polarization rotating elements, and the pixel driver signals provided thereto are selected to produce "bright" output levels at each of the RGB subpixels of the exemplary pixel structure;

Fig. 31A2 is a schematic representation of the LCD panel shown in Fig. 31A1, wherein the pixel driver signals provided thereto are selected to produce "dark" output levels at each of the RGB subpixels of the exemplary pixel structure;

Fig. 31B is a schematic representation graphically illustrating ideal reflection characteristics for the broad-band circularly polarizing (LHCP) reflective panel of the LCD panel of Figs. 31A1 and 31A2, indicating how such a broad-band circularly polarizing panel responds to incident illuminating having circular polarization state LHCP;

Fig. 31C is a schematic representation graphically illustrating ideal reflection characteristics for the broad-band circularly polarizing (RHCP) reflective panel of the LCD panel of Figs. 31A1 and 31A2, indicating how such a broad-band circularly polarizing panel responds to incident illuminating having circular polarization state RHCP;

Fig. 31D is a schematic representation graphically illustrating ideal reflection characteristics for the pass-band circularly polarizing (LHCP) reflective filter element associated with each "blue" subpixel of the LCD panel of Figs. 31A1 and 31A2, indicating how such a non-absorbing spectral filter element responds to incident broad-band illumination having circular polarization state LHCP;

Fig. 31E is a schematic representation graphically illustrating ideal reflection characteristics for the pass-band circularly polarizing (LHCP) reflective filter element associated with each "green" subpixel of the LCD panel of Figs. 31A1 and 31A2, indicating how such a non-absorbing spectral filter element responds to incident broad-band illumination having circular polarization state LHCP;

Fig. 31F is a schematic representation graphically illustrating ideal reflection characteristics for the pass-band circularly polarizing (LHCP) reflective filter element associated with each "red" subpixel of the LCD panel of Figs. 31A1 and 31A2, indicating

how such a non-absorbing spectral filter element responds to incident broad-band illumination having circular polarization state LHCP;

Fig. 32A1 is a schematic representation of an exploded, partially cut-away cross-sectional view of a second illustrative embodiment the generalized CLC-based LCD panel assembly shown in Fig. 31, wherein the spatial-intensity modulating panel is disposed between the backlighting structure and the spectral filtering structure of the system and the spatial-intensity modulating elements employed therein are realized using linear-type polarization rotating elements, and the pixel driver signals provided thereto are selected to produce "bright" output levels at each of the RGB subpixels of the exemplary pixel structure;

Fig. 32A2 is a schematic representation of the LCD panel shown in Fig. 32A1, wherein the spatial-intensity modulating elements of the LCD panel are realized using linear-type polarization rotating elements, and the pixel driver signals provided thereto are selected to produce "dark" output levels at each of the RGB subpixels of the exemplary pixel structure;

Fig. 32B is a schematic representation graphically illustrating the reflection characteristics of the first broad-band linearly polarizing (LP1) reflective panel of the LCD panel of Figs. 32A1 and 32A2, indicating how such a broad-band linearly polarizing reflective panel responds to incident illuminating having linear polarization state LP1;

Fig. 32C is a schematic representation graphically illustrating the reflection characteristics of the second broad-band linearly polarizing (LP1) reflective panel of the LCD panel of Figs. 32A1 and 32A2, indicating how such a broad-band linearly polarizing reflective panel responds to incident illuminating having linear polarization state LP2;

Fig. 32D is a schematic representation graphically illustrating the reflection characteristics of the pass-band linearly polarizing (LP2) reflective filter element associated with each "blue" subpixel of the LCD panel of Figs. 32A1 and 32A2, indicating how such a non-absorbing spectral filter element responds to incident broad-band illumination having linear polarization state LP2;

Fig. 32E is a schematic representation graphically illustrating the reflection characteristics of the pass-band linearly polarizing (LP2) reflective filter element associated with each "green" subpixel of the LCD panel of Figs. 32A1 and 32A2, indicating how such a non-absorbing spectral filter element responds to incident broad-band illumination having linear polarization state LP2;

Fig. 32F is a schematic representation graphically illustrating the reflection characteristics of the pass-band linearly polarizing (LP2) reflective filter element associated



with each "red" subpixel of the LCD panel of Figs. 32A1 and 32A2, indicating how such a non-absorbing spectral filter element responds to incident broad-band illumination having linear polarization state LP2;

Fig. 33 is a schematic representation of an exploded, partially cut away cross-sectional view of an alternative embodiment of the LCD panel construction shown in Figs. 3A1 and 3A2, wherein the spatial-intensity modulating elements of the LCD panel are realized using circular-type polarization rotating elements, the pixel driver signals provided thereto are selected to produce "bright" output levels the red and blue subpixels of the exemplary pixel structure and a "dark" output level at the green subpixel level, and a broad-band absorptive linear polarizer is used in conjunction with each broad-band polarizing reflective panel in the LCD panel in order to provide improved image contrast in the images displayed therefrom

Fig. 34 is a schematic representation of an exploded, partially cut away cross-sectional view of an alternative embodiment of the LCD panel construction shown in Figs. 30A1 and 30A2, wherein the spatial-intensity modulating elements of the LCD panel are realized using linear-type polarization rotating elements, the pixel driver signals provided thereto are selected to produce "bright" output levels the red and blue subpixels of the exemplary pixel structure and a "dark" output level at the green subpixel level, and a broad-band absorptive linear polarizer is used in conjunction with each broad-band polarizing reflective panel in the LCD panel in order to provide improved image contrast in the images displayed therefrom;

Fig. 35 is a schematic representation of an exploded, partially cut away cross-sectional view of an exemplary pixel structure within an alternative embodiment of the LCD panel construction shown in Figs. 32A1 and 32A2, wherein the spatial-intensity modulating elements of the LCD panel are realized using linear-type polarization rotating elements, the pixel driver signals provided thereto are selected to produce "dark" output levels at the red and blue subpixels of the exemplary pixel structure and a "bright" output level at the green subpixel level, and a broad-band absorptive linear polarizer is used in conjunction with each broad-band polarizing reflective panel in the LCD panel in order to provide improved image contrast in the images displayed therefrom;

Fig. 36 is a schematic representation of an exploded, partially cut away cross-sectional view of an alternative embodiment of the LCD panel construction shown in Figs. 31A1 and 31A2, wherein the spatial-intensity modulating elements of the LCD panel are realized using circular-type polarization rotating elements, the pixel driver signals provided thereto are selected to produce "dark" output levels the red and blue subpixels of the

exemplary pixel structure and a "bright" output level at the green subpixel level, and broad-band absorptive circular polarizer is used in conjunction with each broad-band polarizing reflective panel in the LCD panel in order to provide improved image contrast in images displayed therefrom;

Fig. 37A is a schematic representation of a direct-view type image display system, wherein any one of the LCD panel assemblies of the present invention may be embodied;

Fig. 37B is a schematic representation of a projection-type image display system, wherein any one of the LCD panel assemblies of the present invention may be embodied;

Fig. 38 is a schematic representation of a portable color image projection system in the form of a laptop computer, wherein a plurality of conventional backlighting structures are cascaded together and mounted to the rear portion of an LCD panel according to the present invention in order to provide an LCD panel assembly that can be mounted within the display portion of the system housing and project bright images onto a remote surface without the use of an external light source or a rear opening in the display portion of the housing, for projecting light therethrough during its projection-viewing mode of operation;

Fig. 39 is a first CLC-based spectral filtering device constructed in accordance with the present invention, for producing spectrally filtered patterns of linearly polarized light from a source of white unpolarized light, wherein each red subpixel structure therein is realized by a clear (non reflecting) region in the first CLC layer and a green-blue band reflecting region in the second CLC layer, wherein each green subpixel structure therein is realized by a red band reflecting region in the first CLC layer and a blue reflecting region in the second CLC layer, wherein each blue subpixel structure therein is realized by a red-green band reflecting region in the first CLC layer and a clear (non-reflecting) region in the second CLC layer, and wherein a green-blue band reflecting pattern and quarter-wave retardation surface thereover are provided beneath the first CLC layer in order to realize the broad-band inter-subpixel "white" reflective matrix-like pattern between neighboring subpixel regions;

Fig. 40 is a second CLC-based spectral filtering device constructed in accordance with the present invention, for producing spectrally filtered patterns of linearly polarized light from a source of white unpolarized light, wherein each blue subpixel structure therein is realized by a red-band reflecting region in the first (i.e. lower) CLC layer and a green band reflecting region in the second CLC layer, wherein each green subpixel structure therein is realized by a red band reflecting region in the first CLC layer and a blue band reflecting region in the second CLC layer, wherein each red subpixel structure therein is realized by a green band reflecting region in the first CLC layer and a blue-band reflecting region in the second CLC layer, and wherein a green-blue band reflecting pattern and quarter-wave

retardation surface thereover are provided beneath first CLC layer in order to realize the broad-band inter-subpixel "white" reflective matrix-like pattern between neighboring subpixel regions; and

Fig. 41 is a third CLC-based spectral filtering device constructed in accordance with the present invention, for producing spectrally filtered patterns of linearly polarized light from a source of white unpolarized light, wherein each red subpixel structure therein is realized by a clear (non-reflecting) region in the first CLC layer and a blue-green band reflecting region in the second CLC layer, wherein each blue subpixel structure therein is realized by a green-red band reflecting region in the first CLC layer and a clear (non-reflecting) region in the second CLC layer, wherein each green subpixel structure therein is realized by a red band reflecting region in the first CLC layer and a blue-band reflecting region in the second CLC layer, and wherein a broad-band reflecting pattern and quarter-wave retardation surface thereover are provided beneath the first CLC layer in order to realize the broad-band inter-subpixel "white" reflective matrix-like pattern between neighboring subpixel regions.

#### BEST MODES FOR CARRYING OUT THE PRESENT INVENTION

Referring now to the figures in the accompanying Drawings, the illustrative embodiments of the present invention will now be described in detail, wherein like structures and elements shown within the figures are indicated with like reference numerals.

##### Systemic Light Recycling Within The LCD Panel Of The Present Invention

The light transmission efficiency of prior art LCD panels has been severely degraded as a result of the following factors: absorption of light energy due to absorption-type polarizers used in the LCD panels; absorption of light reflected off thin-film transistors (TFTs) and wiring of the pixelated spatial intensity modulation arrays used in the LCD panels; absorption of light by pigments used in the spectral filters of the LCD panels; absorption of light energy by the black-matrix used to spatially separate the subpixel filters in the LCD panel in order to enhance image contrast; and Fresnel losses due to the mismatching of refractive indices between layers within the LCD panels. As a result of such light energy losses, it has been virtually impossible to improve the light transmission efficiency of prior art LCD panels beyond about 5%.

The LCD panel of the present invention overcomes each of the above drawbacks by employing a novel scheme of "systemic light recycling" which operates at all levels of the LCD system in order to avoid the light energy losses associated with prior art LCD panel designs, and thereby fully utilize nearly 100% of the light energy produced by the backlighting structure thereof. While the details of this novel systemic light recycling scheme will be hereinafter described for each of the illustrative embodiments, it will be appropriate at this juncture to briefly set forth the principles of this systemic light recycling scheme.

In each of the embodiments of the present invention, a single polarization state of light is transmitted from the backlighting structure to those structures (or subpanels) of the LCD panel where spatial intensity modulation and spectral filtering function of the transmitted polarized light simultaneously occurs on a subpixel basis and in a functionally integrated manner. At each subpixel location, spectral bands of light which are not transmitted to the display surface during spectral filtering are reflected without absorption back along the projection axis into the backlighting structure where the polarized light is recycled with light energy being generated therewith and then retransmitted from the backlighting structure into section of the LCD panel where spatial intensity modulation and spectral filtering of the retransmitted polarized light simultaneously occurs on a subpixel basis in a functionally integrated manner. At each subcomponent level within the LCD panel, spectral components of transmitted polarized light which are not used at any particular subpixel structure location are effectively reflected either directly or indirectly back into the backlighting structure for recycling with other spectral components for retransmission through the backlighting structure at the operative polarization state, for reuse by both the same and neighboring subpixel structures. The mechanics of this novel systemic light recycling scheme are schematically illustrated in Figs. 3A1, 3A2, 30A1, 30A2, 31A1, 31A2, and 32A1 and 32A2, and will be described in greater detail hereinafter. By virtue of this novel systemic light recycling scheme of the present invention, it is now possible to design and construct LCD panels that can utilize produced backlight with nearly 100% light transmission efficiency, in marked contrast with prior art LCD panels having efficiencies of about 5%.

In the first generalized LCD panel construction shown in Fig. 2, spectral filtering occurs before spatial intensity modulation. In the first illustrative embodiment of this generalized LCD panel construction shown in Figs. 2B through 3F, circular polarization techniques are used to carry out the spatial intensity modulation and spectral filtering functions employed therein. In the second illustrative embodiment of this generalized LCD

panel construction shown in Figs. 29 through 30F, linear polarization techniques are used to carry out the spatial intensity modulation and spectral filtering functions employed therein. In each such illustrative embodiment, modifications will be made among the various components of the generalized LCD panel construction shown in Fig. 2. Details regarding such modifications will be described hereinafter.

In the second generalized LCD panel construction shown in Fig. 31, spectral filtering occurs after spatial intensity modulation. In the first illustrative embodiment of this generalized LCD panel construction shown in Figs. 31A1 through 31F, circular polarization techniques are used to carry out the spatial intensity modulation and spectral filtering functions employed therein. In the second illustrative embodiment of this generalized LCD panel construction shown in Figs. 32A1 through 32F, linear polarization techniques are used to carry out the spatial intensity modulation and spectral filtering functions employed therein.

#### LCD Image Display System of First Generalized Embodiment of the Present Invention

In Fig. 2, the subcomponent structure of the first generalized embodiment of the LCD panel hereof is shown in great clarity. As shown, the first generalized embodiment of the LCD panel 2 comprises: a backlighting structure 7 including a quasi-diffusive reflector 7A, for producing a plane of broad-band light having a substantially uniform light intensity over the x and y coordinate axes thereof; a light diffusive panel 410 for ensuring uniform spatial intensity of light across the surface of the LCD panel assembly; a light condensing (i.e. quasi-collimating) film 400 (e.g. realized using refractive or diffractive technology) for ensuring that the light rays output therefrom are directed within a cone of about  $\pm 20$  or so degrees from the normal vector drawn thereto; a broad-band CLC polarizing reflective panel 8; a pixelated array of polarizing reflective spectral filter elements 10, for spectral filtering of light produced from the backlighting structure; a pixelated array of polarization direction rotating elements 9 for spatial intensity modulation of light produced from the backlighting structure; a broad-band polarizing reflective panel 11 for cooperative operation with the pixelated array of polarization direction rotating elements 9 and the pixelated array of polarizing reflective spectral filter elements 10; and a polarization-state preserving light diffusive film layer 420 for scattering light over a broad range of angles so improve the viewing angle performance from the display screen of the LCD panel. In an alternative embodiment, a broad-band absorptive-type panel can be substituted for broad-band

polarizing reflective panel 11 in order to reduce glare due to ambient light incident upon the LCD panel during operation.

In order to produce high-resolution color images, the spatial period of the pixelated arrays 9 and 10 is selected to be relatively small in relation to the overall length and height dimensions of the LCD panel. In a conventional manner, each pixel structure in the LCD panel is comprised of a red subpixel 13A, a green subpixel 13B and blue subpixel 13C, as illustrated in Fig. 2A. As shown therein, each red subpixel structure 13A comprises a red-band polarizing reflective spectral filtering element 10A which is spatially registered with a first polarization direction rotating element 9A. Each green subpixel structure 13B comprises a green-band polarizing reflective spectral filtering element 10B spatially registered with a second polarization direction rotating element 9B. Each blue subpixel element 13C comprises a blue-band polarizing reflective spectral filtering element 10C spatially registered with a third polarization direction rotating element 9C.

The output intensity (i.e. brightness or darkness level) of each red subpixel structure is controlled by applying pulse-width modulated voltage signal  $V_R$  to the electrodes of its electrically-controlled spatially intensity modulating element. The output intensity of each green subpixel structure is controlled by applying pulse-width modulated voltage signal  $V_G$  to the electrodes of its electrically-controlled spatially intensity modulating element. The output intensity of each blue subpixel structure is controlled by providing pulse-width modulated voltage signal  $V_B$  applied to the electrodes of its electrically-controlled spatially intensity modulating element. By simply controlling the width of the above-described voltages  $V_R$ ,  $V_G$ ,  $V_B$ , the grey-scale intensity (i.e. brightness) level of each subpixel structure can be controlled in a manner well known in the LCD panel art.

#### First Illustrative Embodiment of The First Generalized LCD Panel Construction of the present invention

In the first illustrative embodiment shown in Fig. 2B through 7D3, the backlighting structure 7 is realized by a pair of cold-cathode tungsten filament tubes 7C1 and 7C2 directing light through a Plexiglas panel having a light-leaking surface known in the art, and a light diffusive film 400 for rendering the spatial light intensity uniform across the surface of the panel in a manner known in the art. For illustration purposes, the spectral emission characteristics of the tungsten light sources are taken to be those set forth in Fig. 1C. Understandably, there are other techniques for producing a plane of unpolarized light for use in connection with the LCD panel of the present invention.

In the illustrative embodiment shown in Figs. 2B and 2B1, a light condensing film 410 is applied to the surface of the light diffusive film 400 so that the light rays output from the light condensing film 410 are condensed (e.g. focused) within a cone of light rays confined to about 15-20 degrees about the normal vector drawn to the broad-band CLC reflective polarizing panel 8, without absorbing or otherwise dissipating the light during condensing operations. Notably, it is not necessary for the light condensing film to be a perfect collimator in order to ensure that (i) light rays of a particular polarization state, incident the broad-band CLC reflective polarizer 8, are transmitted therethrough with reduced polarization distortion, and that (ii) light rays incident the CLC-based spectral filtering structure are transmitted therethrough with minimal wavelength shifting as a function of viewing angle, associated with prior art CLC-based LCD panel designs. While it is preferred that the cone of light rays from each point on the light condensing film 410 be confined to about 15-20 degrees from the normal vector, it is understood that the degree of actual light condensation in any particular LCD panel design will take into consideration factors including the total thickness of the individual components as well as the total thickness of the LCD panel so that directly transmitted and recycled light rays fall incident upon the CLC-based spectral filtering structure so that viewing-angle dependent wavelength shifting effects will be minimized. Complex ray tracing models of the light rays propagating within the CLC-based LCD panel construction under design can be constructed and used to arrive at optimal levels of light condensing in any particular embodiment of the present invention.

In general, micro-lens arrays or other light refractive film structures having light condensing powers without significant energy absorption, can be used to realize the light condensing film 410 disposed between the light diffusive layer 400 and the broad-band CLC reflective polarizer 8. In such embodiments, the spatial period of the micro-lens array should have a substantially greater spatial period than the spatial period of the subpixel structures of the CLC-based spectral filtering structure 10. Alternatively, the non-absorbing light condensing film or optical element 410 can also be realized using transmission-type volume holograms as well as other light diffractive optical elements (DOEs) which can condense a spatial distribution of light on a super-subpixel basis, without absorbing energy contained therein.

As shown in Fig. 4, the super-wide-angle CLC-based reflective broadband polarizing panel (i.e. un-patterned film) 8 is provided with several phase compensation layers 140 and 160 attached to the top of the right-handed CLC broadband polarizer 120 facing its long pitch side. As will be described in detail below, the function of these compensation layers is

to ensure that polarized light transmitted by the broad-band CLC polarizing panel 8 does not contain orthogonal light components which result in significant distortion with the LCD panel assembly due to the fact that light rays, incident the broad-band CLC reflective polarizing panel are not substantially normal or perpendicular to the surface thereof. This compensated configuration acts as a super-wide-angle circular analyzer in both transmission and reflection modes. An adhesive 900 with an index of refraction for matching the index of refraction for layers 120 and 140 is used to increase the optical efficiency of the super-wide-angle CLC based reflective broadband circular polarizing film 8. A similar adhesive 910 is used between the layers 140 and 160.

As shown in Fig. 4, compensating layer 160 is a homeotropic film having its molecules lined up with the long axes perpendicular to the surface of the layer as shown in microscopic view 170. Homeotropic layers can be uniaxial films with vertical optical axis, low molecular weight liquid crystal films, or polymerizable liquid crystal films. Homeotropic layer 160 changes the incident circularly polarized light to elliptical with  $\pm 45$ -degree major axis orientation. Layer 140 is an infrared (IR) CLC layer with a helical structure having an axis perpendicular to the surface of layer 140. The pitch of the IR CLC film is outside the reflection band of the broadband polarizer. The CLC film can be any low molecular CLC material, polymerizable CLC material, or material with chiral structure, having constant or variable pitch in the IR region. The CLC material will reflect IR and transmit all other frequencies. The IR CLC layer 140 rotates the major axis and changes the shape of the ellipse so that the polarization state coincides with the eigen-state of the broadband polarizer 120. As Figs. 4A through 4D show, with the configuration in Fig. 4, right-handed circular light is completely reflected, and left-handed circular light is completely transmitted for incident angles up to at least 70 degrees for the entire visible range. Therefore, the CLC-based structure shown in Fig. 4 functions as a super-wide-angle CLC analyzer operating in both transmission and reflection modes. For normal or small angles of incidence  $\theta$ , the transmitted left-handed circular polarized light 220" and reflected right-handed circularly polarized light 210" are approximately the same as without compensating layers 140 and 160 as Figs. 4A through 4D shows, thus preserving the good behavior at small angles. For large angles of incidence  $\theta$ , the eigen-states of the broadband polarizer 120 are elliptical, and thus right-handed circular light 210 is partially reflected, and left-handed circular light 220 is partially reflected. Compensating layers 140 and 160 change the incident left-handed circular (right-handed circular) light to an elliptical state that is completely transmitted (reflected) from the polarizer 120.



The CLC-based structure shown in Fig. 4 also acts as a super-wide-angle CLC polarizer operating in reflection mode. Unpolarized light remains unpolarized when passing through layers 160 and 140. For incident light 200 normal or near normal to the surface, the light 210' reflected from the broadband polarizer 120 is circularly polarized, and it will pass practically unchanged through layers 140 and 160. As before with the uncompensated RH CLC broadband polarizer 120, normal or near normal light will be reflected as light 210" and transmitted as light 220" with values close to the uncompensated light 210' and 220' which are both circularly polarized with opposite handedness.

For incident light 200 at larger angles of incidence, as shown on the left-hand portion of Fig. 4, unpolarized incident light emerges from homeotropic layer 160 as light 200<sub>E1</sub> which is still unpolarized light, it then passes through IR CLC layer 140 and emerges as light 200<sub>E2</sub>, which is still unpolarized light in the visible region. As before, the light is polarized at the right-handed CLC broadband polarizer 120. However, as light 310'<sub>E2</sub> is a mixture of right-handed and left-handed circularly polarized light passes through IR CLC layer 140, it will be acted on and transformed by rotating the major axis to  $\pm 45$  degrees emerging as 310'<sub>E1</sub>. Preferably, the IR CLC layer should be left-handed when combined with a right-handed broadband polarizer, or the order of the two compensation films should be reversed. The light then enters homeotropic layer 160 where it is converted into circularly polarized light emerging as light 310'.

Figs. 4A through 4D graphically show the transmittance of the right-handed 210 and left-handed circularly polarized light 220 at different angles of incidence for the CLC broadband polarizer 120. Figs. 4A through 4D also shows the comparative transmittance compensated by compensation layers 140 and 160. Compensation films 140 and 160 are used to correct for the distortions at large angles of incidence while retaining the characteristics of undistorted light at normal incidence and small angles of incidence.

Figs. 4A through 4D show that when white visible light is used as the unpolarized light 200, the reflected beam 210" for low incident angles and beam 310'<sub>E2</sub> for large incident angles, as seen through a perfect circular analyzer, of the super-wide-angle CLC based broadband circular polarizer, as shown in Fig. 4, is about 50% showing that it is a good polarizer in reflection mode all across the visible spectrum for angles up to at least 70 degrees. As described above, the incident light 200 on the helices 130 of the CLC broadband polarizer 120, when at large angles of incidence, sees an elliptical cross section and not a circular cross section as light normal to the surface would see. Therefore, at oblique incident angles the eigen-states of the uncompensated broadband polarizer 120 are

not circular but elliptical, and the role of the compensation films for the polarizer in reflection mode is to convert the elliptically polarized reflected light 310' back to circular.

In order to achieve saturated reflection and transmission from the broadband polarizer 120 for a large bandwidth, sufficient thickness and large enough birefringence are a prerequisite, as illustrated in the characteristics shown in Fig. 4E. Under these conditions the CLC broadband polarizers 120 exhibit the universal behavior that the light reflected 310' or transmitted 320' through the CLC broadband polarizing film 120 at large incident angles has polarization state such that the orientation of the major axis of the polarization ellipse is either in or perpendicular to the plane of incidence. Light with such a polarization state cannot be converted back to circular by homeotropic films 160 only, because these films exhibit only linear, and not the necessary circular birefringence. Only light that has a major axis orientation of its polarization ellipse at  $\pm 45$  degrees with respect to the incident plane can be successfully converted back to circular at oblique incident angles using homeotropic films with positive and/or negative birefringence.

The major axis orientation of the light reflected from the CLC broadband polarizer 120 can be rotated by the IR CLC film to approximately  $+45$  or  $-45$  degrees. The role of IR CLC layer 140 is to rotate the major axis of the polarization ellipse of reflected light 310' to  $+45$  or  $-45$  degrees, and at the same time change the shape of the ellipse, after which the light can be converted to circular with an appropriate homeotropic film 160.

As shown in Figs. 4F and 4G, the broad-band CLC reflective polarizing panel 8 described above provides the LCD panel system of the present invention with a significant improvement in angular viewing performance, as indicated by the color temperature characteristics plotted as a function of angle of incidence for difference film thicknesses and birefringence measures.

For further details on the construction of the broad-band CLC reflective polarizer 8, reference can be made to International Application PCT/US96/17464 published by WIPO on May 9, 1997 as WO 97/16762, International Application PCT/US96/14264 published by WIPO on January 21, 1999 as WO 99/02346 and International Application No. PCT/US98/03688 on September 3, 1998 as WO 98/38547, incorporated herein by reference as if set forth fully herein.

In Figs. 5 through 5B2, a first illustrative embodiment of the CLC-based spectral filtering structure hereof, indicated by 10A, is shown in greater detail. As shown in Fig. 5A, the CLC spectral filtering structure 10A comprises: a glass plate 100; a patterned layer of patterned CLC broad-band film 101 deposited in the surface of the glass plate 100 and spatially registered with the regions of TFTs and wiring on the spatial intensity modulation

structure 9, between subpixel transmission apertures therewithin; a first CLC layer 102 having two different spectrally-tuned color band regions formed therein; a first barrier layer 103 on the first CLC layer 102; a second CLC layer 104 having two different spectrally-tuned color band regions formed therein; a second barrier layer 105 formed on the second CLC layer 104; a quarter-wave phase retardation layer 106 disposed upon the second barrier layer (i.e. only in those embodiments using a linearly polarizing spatial intensity modulation panel as shown in Fig. 30A1 and 30A2, and 32A1 and 32A2, but not in embodiments using a circularly polarizing spatial intensity modulation panel as shown in Figs. 3A1 and 3A2 and 31A1 and 31A2); a third barrier layer 107 (i.e. only when the quarter-wave phase retardation layer 106 is used); a passivation layer 108; and an unpatterned ITO layer 109, as shown in Fig. 5A

In Fig. 5B1, a complete pixel structure within the two-layer CLC spectral filter structure 10A of Fig. 5A is shown in greater detail. As shown in Fig. 5B1, each blue subpixel structure therein is realized by a green-band reflecting region in the first CLC layer 102 and a red band reflecting region in the second CLC layer 104; each green subpixel structure therein is realized by a blue band reflecting region in the first CLC layer 102 and a red band reflecting region in the second CLC layer 104; and each red subpixel structure therein is realized by a blue band reflecting region in the first CLC layer 102 and a green-band reflecting region in the second CLC layer 104. The patterned broad-band CLC reflective layer 101 provided beneath the first CLC layer 102 on glass plate 100 is shown in greater detail in Fig. 5B2. The function of this broad-band reflective pattern 101 on glass plate 100 is to provide a broad-band inter-subpixel "white or silver" reflective matrix-like pattern between neighboring subpixel regions; in order to improve light recycling off the TFT and associated wiring regions surrounding the light transmission aperture of each and every subpixel realized the liquid crystal (LC) spatial-intensity modulation panel of the LCD panel assembly of Fig. 2. By virtue of the fact that inter-subpixel reflective matrix pattern 101 is made from broad-band CLC film, as taught in US Patent No. 5,691,789, there is no need for quarter-wave retarders as taught in US Patent No. 5,822,029, as polarization state conversion does not occur upon reflection of incident light a broad-band CLC reflective film, in contrast with specular or quasi-specular reflectors made from metallic film material.

Alternative ways of realizing reflective-type inter-subpixel matrix patterns 101 are detailed in alternative embodiments of the CLC-based spectral filter structures of the present invention, namely: in the spectral filter structure of Fig. 10, red-green and blue-green reflecting patterns 143 and 142, respectively, are disposed beneath the intersubpixel boundaries to achieve broad band reflection at the subpixel interface regions; in the spectral

filter of Fig. 11, red-blue reflecting regions are disposed beneath BG reflecting and green-red reflecting regions, and green-blue reflecting regions are disposed beneath green-red reflecting regions and blue reflecting regions to achieve broad band reflection at the subpixel interface regions; and in the spectral filter of Fig. 13, blue-green reflecting regions are spatially overlapped with red reflecting regions, and green-red reflecting regions are spatially overlapped with blue reflecting regions so as to achieve broad band reflection at the subpixel interface regions, without the use of extra CLC reflective film patterns to achieve broad-band reflection at the intersubpixel regions along the surface of the spectral filtering structure.

In Figs. 6A through 6F, actual spectral reflection and transmission characteristics for the first and second CLC layers for a prototype CLC spectral filtering structure are shown. In Figs. 6G through 6I, the actual composite spectral reflection characteristics for the blue-green and red subpixel structures within the prototype CLC spectral filtering structure are shown. In Fig. 6J, the actual composite spectral reflection characteristics for the subpixel structures of the CLC spectral filtering structure are plotted against the spectral emission characteristics for the cold-cathode tungsten illuminated backlighting panel of the first illustrative embodiment. The improved color purity of the prototype CLC spectral filtering structure is indicated by the sample coordinates plotted on the chromaticity diagram shown in Fig. 7A. The improved color gamut of the prototype CLC spectral filtering structure is indicated by the sample coordinates plotted on the chromaticity diagram shown in Fig. 7B. The improved extinction characteristics of the prototype CLC spectral filtering structure are graphically illustrated in the extinction versus wavelength plot shown in Fig. 7C. Notably, the measured coordinates plotted on the chromaticity diagrams of Figs. 7D1 through 7D3, indicate that one can expect significant improvements in the angular performance of the CLC-based LCD panel design of Figs. 2B1 and 2B2 provided that the light condensing film 410 is disposed between the light diffusive layer 400 and the broad-band CLC reflective polarizing panel 8, and the light diffusive layer 400 is applied to the surface of the broad-band polarizing analyzer 11 as shown in Fig. 2 and described hereinabove. In Figs. 7D1 through 7D3, the use of the subsystem comprising light condensing film 410 and light diffusive film 420 is indicated by the label "w/ Condensing/Diffusing Film Layer System" or "w/ CDFLS", whereas non-use thereof is indicated by "w/o CDFLS". Clearly, when using the CDFLS of the present invention, one can expect significant improvements in the angular performance of the CLC-based LCD panel assembly of the present invention (i.e. a significant reduction in color shifts as the viewer views the panel from 0 to 60 degrees away from the normal vector drawn to the surface of the display panel).

As shown in Fig. 3A1 and 3A2, the pixelated polarization rotating array 9 of the first illustrative embodiment is realized as an array of electronically-controlled circular polarization rotating elements 9'' which rotate the circularly polarized electric field from the LHCP direction to the RHCP direction as the light rays are transmitted through the spatially corresponding pixels in the LCD panel. In the illustrative embodiment of Figs. 3A1 and 3A2, each electronically-controlled circular polarization rotating element 9A'', 9B'', 9C'' can be realized as a  $\pi$ -cell, whose operation is by controlled by a control voltage well known in the art. In its electrically-inactive state (i.e. no-voltage is applied), the electric field intensity of light exiting from each  $\pi$  cell is substantially zero and thus a "dark" level is produced. In its electrically-active state (i.e. threshold voltage  $V_T$  is applied), the electric field intensity of light exiting from the cell is substantially non-zero and thus a "bright" subpixel level is produced.

In the illustrative embodiment of Fig. 3A1 and 3A2, the array of spectral filtering elements 10A'', 10B'', 10C'' is realized as an array of pass-band circularly polarizing reflective elements 10'' formed within a single plane. As indicated in Figs. 3A1 and 3A2, each pass-band circularly polarizing reflective element in the pixelated pass-band circularly polarizing panel 10'' has a RHCP characteristic polarization state, whereas the broad-band circularly polarizing reflective panel 8'' adjacent backlighting panel 7 has an LHCP characteristic polarization state and the broad-band circularly polarizing reflective panel 11'' has a characteristic polarization state RHCP.

As shown in Fig. 3D, each pass-band polarizing reflective element 10C'' associated with a "blue" subpixel in the pixelated pass-band circularly polarizing panel 10'' is particularly designed to reflect nearly 100% all spectral components having the RHCP characteristic polarization state and wavelengths within the green reflective band  $\Delta\lambda_G$  and the red reflective band  $\Delta\lambda_R$ , whereas all spectral components having the RHCP characteristic polarization state and a wavelength within the blue reflective band  $\Delta\lambda_B$  are transmitted nearly 100% through the pass-band polarizing reflective element. The pass-band polarizing reflective element associated with each "blue" subpixel is "tuned" during fabrication in the manner described hereinabove.

As shown in Fig. 3E, each pass-band polarizing reflective element 10B'' associated with a "green" subpixel in the pixelated pass-band circular polarizing panel 10'' is particularly designed to reflect nearly 100% all spectral components having the RHCP

characteristic polarization state and wavelengths within the red reflective band  $\Delta\lambda_R$  and the blue reflective band  $\Delta\lambda_B$ , whereas all spectral components having the RHCP characteristic polarization state and a wavelength within the green reflective band  $\Delta\lambda_G$  are transmitted nearly 100% through the pass-band polarizing reflective element. The pass-band polarizing reflective element associated with each "green" subpixel is "tuned" during fabrication in the manner described hereinabove.

As shown in Fig. 3F, each pass-band polarizing reflective element 10A" associated with a "red" subpixel in the pixelated pass-band circular polarizing panel 10" is particularly designed to reflect nearly 100% all spectral components having the RHCP characteristic polarization state and wavelengths within the green reflective band  $\Delta\lambda_G$  and the blue reflective band  $\Delta\lambda_B$ , whereas all spectral components having the RHCP characteristic polarization state and a wavelength within the red reflective band  $\Delta\lambda_R$  are transmitted nearly 100% through the pass-band polarizing reflective element. The pass-band polarizing reflective element associated with each "red" subpixel is "tuned" during fabrication in the manner described hereinabove.

The preferred method of making broad-band circular polarizing reflective panels 8" and 11" shown in Figs. 3A1 and 3A2 are disclosed in International Application PCT/US96/17464 published by WIPO on May 9, 1997 as WO 97/16762, International Application PCT/US96/14264 published by WIPO on January 21, 1999 as WO 99/02346 and International Application No. PCT/US98/03688 on September 3, 1998 as WO 98/38547. The pixelated pass-band circularly polarizing reflective panel 10" can be fabricated in a manner similar to the way described in LCD panel fabrication method described in detail hereinabove.

In order to maximize the light transmission efficiency of the LCD panel of Figs. 3A1 and 3A2, moved reflective-type color spectral filter structures having integrated "black" and "white" subpixel marks are employed in the LCD panel construction of the present invention. As will be taught in greater detail hereinafter, a broad-band CLC reflective film pattern is effectively formed (i.e. provided) over the light blocking region of each subpixel region on the backside of the reflective-type color/spectral filter structures employed in each LCD panel. In the first illustrative embodiment described above, a pattern of broad-band multi-layer reflective film, corresponding to the light blocking portions of the subpixel regions, is effectively provided on to the back surface of the broad-band polarizing reflective

panel 8" (facing the backlighting structure) or pixelated spectral filtering panel 10", in spatial registration with the light blocking portions of the subpixel regions. This broadband reflective film pattern provides a light reflective mask which prevents the absorption and scattering of produced light from structures associated with the light blocking portion of the subpixels of the LCD panel.

In order to reduce glare at the surface of the LCD panel due to ambient light incident thereon, a broad-band absorptive film material is effectively formed (i.e. provided) over the light blocking region 51 of each subpixel region on the front surface of the reflective-type color filter structure employed in each LCD panel. In the first illustrative embodiment described above, a pattern of broad-band absorption film, corresponding to the light blocking portions of the subpixel regions, is effectively provided on the front surface of the broad-band polarizing panel 11", in spatial registration with the light blocking portions of the subpixel regions. This provides a light reflective mask which prevents reflection and scattering of ambient light off structures associated with the light blocking portion of the subpixels of the LCD panel, and thus reduces glare at the surface of the LCD panel due to ambient light incident thereon.

Having described in the first illustrative embodiment of the generalized LCD panel construction illustrated in Fig. 2, it is appropriate at this juncture to now describe the operation of its subcomponents with reference to the exemplary pixel structure detailed in Figs. 3A1 and 3A2.

As shown in Figs. 3A1 and 3A2, unpolarized light is produced within the backlighting structure and is composed of spectral components having both LHCP and RHCP polarization states. Only spectral components within the backlighting structure having the RHCP polarization state are transmitted through the broad-band circularly polarizing reflective panel 8" adjacent the backlighting structure 7, whereas spectral components therewithin having polarization state LHCP incident thereon are reflected therefrom without energy loss or absorption. Spectral components reflecting off broad-band circularly polarizing reflective panel 8" on the backlighting structure side strike quasi-diffusive reflector 7A and undergo a polarization inversion (i.e. LHCP to RHCP and RHCP to LHCP). This reflection process occurs independent of wavelength. Only spectral components having the RHCP polarization state are retransmitted through the broad-band circularly polarizing reflective panel along the projection axis of the LCD panel.

In general, as shown in Fig. 3A1 and 3A2, light emitted from the backlighting structure 7 is passed through the non-absorbing light diffusive layer 400 and then through the light condensing film or optical structure 410 so that, as shown in Fig. 2B2, the light

rays are condensed within a cone of rays (within about 10-20 degrees from the normal) through the broad-band reflective polarizer 8, and thereafter, enters the CLC-based spectral filter 10 for spectral filtering operations. The pixelized pattern of spectrally filtered light then passes through liquid crystal spatial-intensity modulation panel 9 (e.g. operating on circularly polarized in Figs. 3A1 and 3A2 but linearly polarized light in Figs. 30A1 and 30A2) so as to modulate the spatial intensity of the spectrally filtered light pattern. The light transmitted from the spatial-intensity modulation panel 9 then passes the spatial intensity modulated distribution of light through a broad-band polarizing panel 11, and then through polarization-preserving light diffusing panel 420, such as a frosted glass diffuser, to produce a color image for viewing by a user of the display panel. Notably, the broad-band polarizing analyzer 11 and the light diffusing panel 420 may be placed in the display panel in reverse order. Light rays emanating from backlighting structure will emerge as colored light circularly polarized and have a large viewing angle without distortion of its color when viewed from different viewing angles.

In the illustrative embodiment frosted glass diffuser can be used to realize the polarization preserving light diffuser. This light diffusing panel 420 is necessary to increase the viewing angle when a light condensing structure 410 is jointly used to better control the light incident angle onto the reflective CLC spectral filter 10A.

By using broad-band reflective polarizer 8 of the present invention, the display panel system hereof reduces the color distortions at large viewing angles. In combination, these subcomponents cooperate to provide a CLC-based LCD panel assembly having markedly improved performance characteristics unavailable using prior art principles.

Having provided a general overview of the LCD panel system of Fig. 2, it is appropriate at this juncture to describe the operation of this system in greater detail herein below.

When a circular polarization rotating element associated with a red-green or blue subpixel is driven into its active-state as shown in Fig. 3A1, the circular polarization rotating element associated therewith transmits the spectral components therethrough independent of wavelength while effecting an orthogonal conversion in polarization state (i.e. LHCP to RHCP and RHCP to LHCP), thereby producing a "bright" subpixel level in response to the active-state into which it has been driven.

When a "red" subpixel is driven into its "bright" state shown in Fig. 3A1, spectral components within the backlighting structure having wavelengths within the "red" band  $\Delta\lambda_r$  and polarization state RHCP (i.e.  $\lambda_r^{RHCP}$ ) are transmitted through the broad-band



circularly polarizing reflective panel 8", the "red" pass-band circularly polarizing reflective element 10A", the circular polarization direction rotating element 9A", and the broad-band circularly polarizing reflective panel 11" without absorption. The "green" and "blue" spectral components with the RHCP polarization state (i.e.  $\lambda_G^{RHCP}$ ,  $\lambda_B^{RHCP}$ ) are transmitted through the broad-band linearly polarizing reflective panel 8" and reflected off the "red" pass-band circularly polarizing reflective element 10A", and are retransmitted through the broad-band circularly polarizing reflective panel 8" back into the backlighting structure for recycling among neighboring subpixels.

When a "green" subpixel is driven into its "bright" state shown in Fig. 3A1, spectral components having wavelengths within the "green" band and polarization state RHCP (i.e.  $\lambda_G^{RHCP}$ ) are transmitted through the broad-band circularly polarizing reflective panel 8", the "green" pass-band circularly polarizing reflective element 10B", the circular polarization direction rotating element 9B", and the broad-band circularly polarizing reflective panel 11" without absorption. The "red" and "blue" spectral components with the RHCP polarization state (i.e.  $\lambda_R^{RHCP}$ ,  $\lambda_B^{RHCP}$ ) are transmitted through the broad-band circularly polarizing reflective panel 8" and reflected off the "green" pass-band circularly polarizing reflective element 10B", and are retransmitted through the broad-band circularly polarizing reflective panel 8" back into the backlighting structure for recycling among neighboring subpixels.

When a "blue" subpixel is driven into its "bright" state shown in Fig. 3A1, spectral components within the backlighting structure having wavelengths within the "blue" band  $\Delta\lambda_B$  and polarization state RHCP (i.e.  $\lambda_B^{RHCP}$ ) are transmitted through the broad-band linear polarizing reflective panel 8', the "blue" pass-band circularly polarizing reflective element 10C", the circular polarization direction rotating element 9C", and the broad-band circularly polarizing reflective panel 11" without absorption. The "red" and "green" spectral components with the RHCP polarization state (i.e.  $\lambda_R^{RHCP}$ ,  $\lambda_G^{RHCP}$ ) are transmitted through the broad-band circularly polarizing reflective panel 8" and reflected off the "blue" pass-band circularly polarizing reflective element 10C", and are retransmitted through the broad-band circularly polarizing reflective panel 8" back into the backlighting structure for recycling among neighboring subpixels.

When a circular polarization rotating element is controlled in its inactive-state as shown in Fig. 3A2, the polarization rotating element transmits the spectral components

therethrough independent of wavelength without effecting a conversion in polarization state, thereby producing a "dark" subpixel level.

When a "red" subpixel is driven into its "dark" state as shown in Fig. 3A2, spectral components within the backlighting structure having wavelengths within the "red" band  $\Delta\lambda_R$  and a polarization state RHCP (i.e.  $\lambda_R^{RHCP}$ ) are transmitted through the broad-band circularly polarizing reflective panel 8'', the "red" pass-band circularly polarizing reflective element 10A'' and the circular polarization rotating element 9A'' and reflected off the broad-band circularly polarizing reflective panel 11'' without absorption. In this state, these reflected spectral components are then retransmitted through the circular polarization rotating element 9A'', the "red" pass-band circular polarizing reflective element 10A'' and the broad-band circularly polarizing reflective panel 8'' back into the backlighting structure for recycling among the neighboring subpixels.

Spectral components within the backlighting structure having wavelengths within the "green" band  $\Delta\lambda_G$  or "blue" band  $\Delta\lambda_B$  and a polarization state RHCP (i.e.  $\lambda_G^{RHCP}$ ,  $\lambda_B^{RHCP}$ ) are transmitted through the broad-band circularly polarizing reflective panel 8'' and are reflected off the "red" pass-band circularly polarizing reflective element 10A'' and retransmitted through the broad-band circularly polarizing reflective panel 8'' back into the backlighting structure for recycling among neighboring subpixels.

When a "green" subpixel is driven into its "dark" state as shown in Fig. 3A2, spectral components within the backlighting structure having wavelengths within the "green" band  $\Delta\lambda_G$  and a polarization state RHCP (i.e.  $\lambda_G^{RHCP}$ ) are transmitted through the broad-band circularly polarizing reflective panel 8'', the "green" pass-band circularly polarizing reflective element 10B'', and the circular polarization rotating element 9B'' and reflected off the broad-band circularly polarizing reflective panel 11'' without absorption. In this state, these reflected spectral components are then retransmitted through the circular polarization rotating element 9B'', the "green" pass-band circular polarizing reflective element 10B'' and the broad-band circularly polarizing reflective panel 8'' back into the backlighting structure for recycling among the neighboring subpixels. Spectral components within the backlighting structure having wavelengths within the "red" band  $\Delta\lambda_R$  or "blue" band  $\Delta\lambda_B$  and a polarization state RHCP (i.e.  $\lambda_R^{RHCP}$ ,  $\lambda_B^{RHCP}$ ) are transmitted through the broad-band circularly polarizing reflective panel 8'' and are reflected off the "green" pass-band circularly polarizing reflective element 10B'' and retransmitted through the broad-

band circularly polarizing reflective panel 8" back into the backlighting structure for recycling among neighboring subpixels.

When a "blue" subpixel is driven into its "dark" state as shown in Fig. 3A2, spectral components within the backlighting structure having wavelengths within the "blue" band  $\Delta\lambda_B$  and a polarization state RHCP (i.e.  $\lambda_B^{RHCP}$ ) are transmitted through the broad-band circularly polarizing reflective panel 8", the "blue" pass-band circularly polarizing reflective element 10C", and the circular polarization rotating element 9C" and reflected off the broad-band circularly polarizing reflective panel 11" without absorption. In this state, these reflected spectral components are then retransmitted through the circular polarization rotating element 9C", the "blue" pass-band circularly polarizing reflective element 10C" and the broad-band circularly polarizing reflective panel 8" back into the backlighting structure for recycling among the neighboring subpixels. Spectral components within the backlighting structure having wavelengths within the "red" band  $\Delta\lambda_R$  or "green" band  $\Delta\lambda_G$  and a polarization state RHCP (i.e.  $\lambda_R^{RHCP}$ ,  $\lambda_G^{RHCP}$ ) are transmitted through the broad-band circularly polarizing reflective panel 8" and are reflected off the "blue" pass-band circularly polarizing reflective element 10C" and retransmitted through the broad-band circularly polarizing reflective panel 8" back into the backlighting structure for recycling among neighboring subpixels.

#### Methods For Making The CLC-Based Spectral Filters Of The First Illustrative Embodiment

Referring now to Figs. 8A through 8D4, several preferred methods will now be described for fabricating the CLC-based spectral filtering structure shown in Figs. 5 through 5B2, including the LCD panel shown in Figs. 2, 3A1 and 3A2.

As shown in Fig. 8A, the reflective spectral filter 10A can be made by making the first and second CLC layers 102 and 104 individually and then combining them in a desired manner. To make the left-handed reflective cholesteric liquid crystal (CLC) color filter of layer 102, first, prepare a bottom substrate 210 made of PVA (polyvinyl alcohol) coated glass plate, and buffing it in one direction. Then, prepare a top substrate 212 of PET (Mylar D) by buffing it in any direction.

Then mix a left-handed CLC polymer comprising blue polysiloxane, such as that sold by Wacker Chemical Company of Germany as SLM 90032, 84.1% by weight, with a low molecular weight nematic liquid crystal, such as that sold by EMI Company of Germany as (E44, EMI): 14.8% by weight. Then add a left-handed chiral dopant, such as that sold by EMI Company of Germany as (S1011, EMI), 0.1% by weight of total polysiloxane and

nematic and photo initiator (IG184, Ciba-Geigy), 1% by weight of polysiloxane. Mix the above materials at 120° C and de-gas the mixture in a vacuum for 20 minutes at a temperature around 90°C.

The mixture is then coated onto the PVA coated glass bottom substrate 210 with the use of a knife coater. The coating is preferably about 8–12 microns thick. The coating temperature and the gap of the knife coater can be used to vary the thickness of the coating as applied.

The mixture is then laminated with the PET top substrate 212 using a laminator. The temperature and the gap between the rollers of the laminator will effect the final thickness of the film.

To make a CLC film with blue subpixel 217 and green subpixel 218 in layer 102, layer 102 is heated at 100° C with the PET substrate 212 up, the heating is preferably done on a hot plate.

With the layer 102 at 100° C it is preferable to mechanically shear the top substrate 212 downward with respect to the bottom substrate 210. The mechanical shearing provides a tangential mechanical force which helps align the liquid crystal molecules between substrates 210 and 212 in layer 102.

With layer 102 still on the hot plate or still heated to 100° C, apply a mask to the top substrate layer 212 having the PET material.

The mask will vary in size and shape depending on the use of the layer. For use in color displays the mask will be the size and shape of pixels used in the display. In the layer shown in Fig. 8A the CLC-based filter 300 uses two layers with two reflection colors per layer. The pixel sizes may vary in size within the layer. For example as two subpixels of blue 217 are used side by side only one large subpixel needs to be made, however two subpixels may also be used in the same space for the blue subpixel portion 217 in layer 102.

A mask is applied to block the portion of layer 102 to be the green subpixel 218 leaving blue subpixels 217 exposed.

While still at 100° C layer 102 is exposed to UV light of about (360 nm) at 2.77 mW/cm<sup>2</sup> intensity for approximately 17 seconds to polymerize the exposed cholesteric liquid crystals in the blue subpixels 217 of layer 102.

Layer 102 is then heated at 61° C preferably on a hot plate for about 5 minutes to control broadening of the bandwidth of the blue subpixel 217 of layer 102. The bandwidth is a function of the pitch gradient of the cholesteric liquid crystal material.

While at 61° C the mask is removed and layer 102 is exposed to UV light of about 360 nm at 1.00 mW/cm<sup>2</sup> for approximately 150 seconds to polymerize the green subpixel 218 of layer 102 with the desired bandwidth.

Maintaining 61° C layer 102 is then exposed to UV light of 360 nm at 20 mW/cm<sup>2</sup> for approximately 60 seconds to set the polymers of both the blue subpixels 217 and the green subpixel 218. The PET substrate 212 is then removed. Layer 102 is now ready for installation in a display or for other use.

To make left-handed reflective cholesteric liquid crystal (CLC) color filter reflecting the green subpixel 227 and red subpixels 228 of layer 104, first, prepare a bottom substrate 220 of PVA (polyvinyl alcohol) coated glass, by buffing it in one direction. Then, prepare a top substrate 221 of PET (Mylar D) by buffing it in any direction.

Mix a left-handed CLC polymer comprising blue polysiloxane, such as that sold by Wacker Chemical Company of Germany as SLM 90032, 79% by weight, with a low molecular weight nematic liquid crystal, such as that sold by EMI Company of Germany as (E44, EMI): 20% by weight. Then add a photo-initiator (IG184, Ciba-Geigy), 1% of the CLC polymer SLM 90032. The above materials are mixed at 120° C and de-gassed in a vacuum for 20 minutes at 90°C.

The mixture is then coated onto the PVA coated glass bottom substrate 220 with the use of a knife coater. The coating is preferably about 8-12 microns thick. The coating temperature and the gap of the knife coater can be used to vary the thickness of the coating as applied. The mixture is then laminated with the PET top substrate 221 using a laminator. The temperature and the gap between the rollers of the laminator will effect the final thickness of the film.

To make a CLC film with red 228 and green 227 subpixels in layer 104, layer 104 is heated to 58° C with the PET substrate 221 up, the heating is preferably done on a hot plate.

With the layer 104 at 58° C it is preferably mechanically sheared to make the liquid crystal molecules aligned. The mechanical shearing provides a tangential mechanical force which helps align the liquid crystal molecules between substrates 220 and 221 in layer 104. With layer 104 still on the hot plate or still heated to 58° C, apply a mask to the top substrate layer 221 having the PET material. The mask will vary in size and shape depending on the use of the layer. For use in color displays the mask will be the size and shape of pixels used in the display. In the layer shown in Fig. 8A the CLC-based spectral filter 300 uses two layers with two colors of reflective color filters per layer.

The pixel sizes may therefore vary in size within the layer. For example as two subpixels of red are used side by side only one large subpixel need be made, however two subpixels may also be used in the same space for the red subpixel 228 in layer 104.

The mask is applied to block the portion of the layer 104 to be the green subpixel 227 leaving exposed red subpixels 228.

While still at 58° C layer 104 is then exposed to UV light of 360 nm at 1.0 mW/cm<sup>2</sup> intensity for approximately 77 seconds to polymerize the exposed cholesteric liquid crystals in the red subpixel 228 of layer 104.

Layer 104 is then heated at 83° C preferably on a hot plate for about 5 minutes to control broadening of the bandwidth of the red subpixel 228 of layer 104.

The mask is then removed and layer 104 is held at 70° C while being exposed to UV light 360nm at 20 mW/cm<sup>2</sup> for approximately 60 seconds to polymerize the green subpixel 227 of the layer 104 with the desired bandwidth.

The PET substrate 221 is then removed. Layer 104 is now ready for installation in a display or for other use.

As shown in Fig. 8B the layers 102 and 104 can be laminated together to form a two layer color filter for a display.

In order to make a display, layer 104 is glued to a reflective matrix substrate 101 preferably by using a UV curable adhesive. The pixels of the red-green layer 104 are first aligned with the broad-band CLC reflective matrix 101. Then a strong UV light at 20 mW/cm<sup>2</sup> is used to cure the glue for approximately 60 seconds. Then heat layer 104 and reflective matrix 101 are heated for approximately 30 seconds at 65° C. The glass substrate 220 of the green-red reflecting layer 104 is then peeled off and a UV curable adhesive is applied to the top of layer 104 so as to attach layer 102 thereto. The pixels are then aligned and the glue cured with UV light at 20 mW/cm<sup>2</sup> for approximately 60 seconds.

There are several alternative ways of realizing the basic CLC spectral filtering structure depicted in Figs. 5B through 5B2. These alternative ways will be considered below.

In Fig. 8C, a second alternative method of fabricating the CLC-based spectral filtering structure shown in Fig. 5B, wherein the subpixel structures of each pixel structure therein are arranged in a 3x1 array, and the order of the subpixel structures in neighboring pixel structures are periodically reversed to enable manufacturer of CLC layers having double-sized color-band reflection regions.

Fig. 8C shows an embodiment of the method for patterning the color filter in each layer associated with Fig. 5B1. Instead of patterning "green", "green", and "red" (R,R,G) in

layer 40 in Fig. 5B1 it can be patterned into G,G,R,R,R,G,G,R,R,R,G,G, . Similarly, layer 50 can be patterned to be B,B,B,B,G,G,B,B,B,B,G,G..., where "R", "G" and "B" refer to the filter layer portion reflecting red-green, and blue light, respectively. If the two layers are aligned in the way as shown in Fig. 16, color filter pixels consist of subpixels ( $R_i$ ,  $G_i$ ,  $B_i$ ) and ( $B_i$ ,  $G_i$ ,  $R_i$ ) will be formed, where " $R_i$ ", " $G_i$ ", and " $B_i$ " refer to the red-green, and blue subpixels in transmission. This method for patterning has the advantage of creating the patterned color portion on each layer with a size twice and four times larger than the display subpixel ( $R_i G_i B_i$ ) size. The subpixels of red (R) can then be made as one large pixel instead of 4 small separate subpixels making it easier to fabricate the display. Similarly 4 blue(B) subpixels are made as one large pixel and two subpixels of green G are made as one pixel.

In Figs. 8D1 through 8D4 show a third alternative method of fabricating the CLC-based spectral filtering structure shown in Fig. 5B1, wherein the subpixel structures of each pixel structure therein are arranged in a 2x2 array.

In order to eliminate all reflection at the interfaces between the various parts, index matching techniques should be used. In some cases, this can be simply achieved by gluing the parts together. This by itself will reduce the amount of reflection by a factor of almost 100. Alternatively, a transparent fluid (glycerol) can be disposed between the component parts for index matching. If even greater attenuation of such reflections is required the index of refraction ( $n$ ) of the fluid or glue should be intermediate between the index values of the adjacent materials. For example: if  $n_{BBP}=1.6$  and  $n_{GLASS}=1.5$  the least reflection will occur for a glue/fluid of index:  $n = \sqrt{n_{BBP}n_{GLASS}} = 1.549$ .

#### Alternative Embodiments Of CLC-Based Spectral Filtering Structures For Use In The First Generalized LCD Panel Of The Present Invention

Having described how to make CLC spectral filters for use in the LCD panel assemblies, such as shown in Figs. 5 through 5B2, a number of alternative embodiments come to mind.

To improve the quality of the transmitted light for a display, each color section reflecting red green and blue used in layers 40 and 50 is made with cholesteric liquid crystals which have sharply defined bands of color matched to the colors produced in the light source 100. With a narrow band of color transmitted, color images with improved color purity and better contrast are produced. Fig. 6J shows that cholesteric liquid crystals can be made for tuning the color around a narrow band from a central wavelength. Details of how to make such cholesteric liquid crystals are disclosed in WIPO Publication WO 99/02340, published by Applicant's International Application PCT/US99/14264, which is

incorporated herein by reference. In order to cover the correct bandwidth, the CLC bandwidth needs to be appropriately broadened. For example, in order to reflect the red portion of the light from 600 to 750nm, a CLC with a bandwidth of 150nm is required. However, a natural CLC can cover only 100nm at the most. Such broadband reflective cholesteric liquid crystals are made by the method as shown in International Application PCT/US96/17464 published by WIPO on May 9, 1997 as WO 97/16762, International Application PCT/US96/14264 published by WIPO on January 21, 1999 as WO 99/02346 and International Application No. PCT/US98/03688 on September 3, 1998 as WO 98/38547, which is incorporated herein by reference.

Although this spectral filtering device 101 is shown with left-handed CLC polymers, it is understood that right-handed polymers could also be used to produce a device with opposite handedness light being transmitted. In another embodiment of the present invention, the blue-green and red-green layers 102 and 104 respectively may be used in reverse order and the display will still function in the same way.

In addition to the above separate layers of cholesteric liquid crystal materials glued together, a single layer of cholesteric liquid crystal material with a top portion reflecting one color and a bottom portion reflecting another color, or multiple portions of cholesteric liquid crystal materials polymerized for different functions, can be all stacked in one layer. Pitch gradient CLC materials for use in making the spectral filters hereof are disclosed in copending International Application PCT/US96/17464 published by WIPO on May 9, 1997 as WO 97/16762, International Application PCT/US96/14264 published by WIPO on January 21, 1999 as WO 99/02346 and International Application No. PCT/US98/03688 on September 3, 1998 as WO 98/38547, is incorporated herein by reference in its entirety.

By polymerizing different portions of layers by depth of penetration of UV radiation at different temperatures, discrete portions of a linear stack in a layer of CLC materials can be formed with different optical properties. With a continuous change in temperature and a continuous change in frequency of UV light to change the depth of penetration of UV light, broadband reflective cholesteric liquid crystal color filters can be formed.

Such pitch control techniques can be used to make a fourth illustrative embodiment of the spectral filter structure herein shown in Fig. 10, wherein narrow-band blue-reflecting CLC material of pitch B217 and a narrow-band green-reflecting CLC material of pitch G218 are formed in a top portion 301 of layer 300, whereas a narrow-band green-reflecting CLC material of pitch G 227 and a narrow-band red-reflecting CLC material of pitch R 228 are formed in a bottom portion 302 of layer 300.



In this example, assume the cholesteric liquid crystals are left-handed circularly polarized. The pitch of a cholesteric material can be tuned by varying the sample temperature:  $P(T)$ . Starting with the bottom portion 302 of layer 300 a mixture of cholesteric liquid crystal material at one temperature has a pitch  $P(T_L) = P_R$  reflecting red 228. With other portions of the layer 300 masked, the red 228 portion of layer 302 is exposed to UV light of a specific wavelength which penetrates approximately half way through the layer 300 before it is totally attenuated. This UV light polymerizes the red portion 228 of layer 300. The mask on the bottom portion 302 is removed revealing the green portion 227. At a different temperature either higher or lower than the temperature polymerizing the CLC material for red 228 the temperature for polymerizing green 227 reflective CLC material is reached. UV light of a specific wavelength is then irradiated on the green portion 227 as above for the red 228, such that the UV light is attenuated half way through the layer 300. The bottom portion 302 of layer 300 is now polymerized. Layer 300 may be turned over. A mask is applied covering the blue portion 217. The green portion 218 of layer 301 is polymerized by UV light at a UV wavelength which is attenuated half way through layer 301. Alternatively a mask applied to the bottom layer 302 can be used and a UV light which will penetrate layer 302 to polymerize layer 301 can be used. With the temperature again adjusted to the temperature for reflecting blue light. The mask covering the blue portion 217 is removed and the layer 301 is exposed to UV light at a wavelength to penetrate half way through layer 300.

If a layer is only partially polymerized at one temperature, then only part of the molecules acquire a periodicity for the color desired. When the temperature is changed, the LC molecules that are not strongly anchored yet by the partial cross-linking, must adopt a different pitch. This pitch will not be the same as before since, in the new environment they interact not only with free molecules like themselves, but also with the strongly anchored LC molecules due to the previous partial polymerization process.

With a series of small steps in temperature variation and UV penetration, wavelengths, a broadband of spectral components will be reflected by the layer 300. Each incremental portion of layer 300 will have a band about a central wavelength that it reflects. With a continuous change in temperature linked to a continuous change in UV penetration wavelength, broadband reflective cholesteric liquid crystal color filters can be made about a central wavelength. Therefore broadband polarizers may be made with variable pitch cholesteric liquid crystal materials by varying the temperature gradient and UV penetration gradient in a coordinated manner, for example, by changing the temperature of a hotplate in

conjunction with changing the UV frequency such that the change in pitch in the cholesteric liquid crystal material is polymerized for a broadband reflective CLC material layer.

The above technique can be used to make the spectral filter shown in Fig. 14. In this filter structure, the broadband reflective portions for red-green reflecting regions 121 and for green-blue reflecting regions 113 can be made using the above process of masking and changing temperatures while changing the UV wavelength to penetrate half way through layer 300. Thus the upper portion 301 of layer 300 has a blue reflecting subpixel 117 and a green-blue reflecting subpixel 113 and a clear isotropic subpixel 114. The bottom portion 302 of layer 300 is polymerized to have a red reflecting subpixel 127, a red-green reflecting subpixel 121 and a clear subpixel 124.

As shown in Fig. 14, the light transmitted through layer 300 will have: a red subpixel portion; a white reflective portion made by overlapping the red-green portion 121 with the blue portion 117 automatically forming a reflective-type intersubpixel matrix; a green subpixel portion; another reflective-type intersubpixel portion made by overlapping the red-green reflecting portion 121 with the green-blue reflecting portion 113 automatically forming a reflective matrix and a blue subpixel portion; and a third black portion made by overlapping the green-blue portion 113 with the red portion 127 automatically forming a reflective-type interpixel matrix. Since all of these regions are realized on single layer of material, the process for making CLC-based LCD panels is simplified by requiring fewer layers, and fewer gluing and aligning steps to make a final display panel.

Since the penetration of the UV light is attenuated differently at different frequencies several distinct portions providing different functions can be stacked in a single layer of CLC material.

By using the methods described above for masking and polymerizing, each subpixel emitting a color can also be provided with its own zero-order quarter-wave plate pixel tuned to that color. Or in another embodiment, one quarter-wave plate 155 can be geared for all the colors transmitted by the reflective portions of the layer. The quarter-wave plate portion 155 can be polymerized by a different wavelength than the other portions of the layer and can therefore be polymerized before layer 301.

For example, for a layer of aligned nematic mixture, which is not polymerized, a UV light with a shorter penetration length is used to polymerize a small depth into the layer. Exposing the film through a mask, the temperature and the exposure times are adjusted so as to polymerize only a thin nematic sub-layer (about  $2\ \mu\text{m}$ ). The sample's temperature is set such that when the pixel is polymerized through the mask it would become a 0-order  $\lambda/4$  portion of the layer for the red subpixel. The mask is then shifted to expose the position of

the Green subpixels and temperature-time are adjusted to create a 0-order  $\lambda/4$  portion of the layer for the green subpixel. The same is done for the Blue subpixels. The temperature is then raised to the isotropic phase and the whole sample is flooded with a longer wavelength to achieve a deeper penetration. During this step the remaining unpolymerized LC molecules, within the  $\lambda/4$  portion, are polymerized into an isotropic state so that the retardation of the nematic layer will not be changed by successive UV exposures. This step also creates an additional thin polymerized isotropic portion of the layer that "seals" the top  $\lambda/4$  portion from the rest of the yet unpolymerized mixture below. Clearly, the top substrate must be UV transparent and have a low sticking coefficient to the polymerized portion of the layer.

Alternatively, rather than changing temperature for each color (which may be time consuming), the short UV wavelength can be varied with filters so as to change the effective penetration length. In this method, each  $\lambda/4$  subpixel is the same (since the temperature is fixed) while its effective thickness is varied by the UV wavelength. The step of isotropic "sealing" is the same in both methods.

Once the  $\lambda/4$  portion is fabricated at the top  $2\ \mu\text{m}$  (and supported by an alignment film the top substrate) fabrication of the color filters themselves in the bulk of the layer below can start according to the process outlined before. However, in the presence of an isotropic portion at the top of the substrate, the color filter alignment will have to rely only on the bottom substrate alignment portion.

There are contradictory demands on the mixture components: fabrication of the  $\lambda/4$  portion requires a nematic polymer while the color filter below requires a cholesteric polymer. This can be resolved by using a nematic LC polymer doped with a chiral component. Since the fabrication of the  $\lambda/4$  portion calls for UV exposure with a very large gradient inside the mixture, the chiral component is driven out from the top  $2\ \mu\text{m}$  by diffusion to recover the nematic phase. The color filter fabrication process is carried out using UV light having a very long wave-length, and a uniform intensity distribution throughout the sample to avoid driving a diffusion process.

The above two fabrication methods for the  $\lambda/4$  portion can be also implemented using the current pitch-gradient process when the requirements for a nematic polymer are satisfied.

Instead of having two separate layers 102 and 104 on separate films, as shown in Fig. 8A, spectrally tuned CLC regions can be formed on one layer having its top portion polymerized with one bandwidth around one wavelength and its bottom portion polymerized with a second bandwidth around a second wavelength. Therefore two-color

band reflection regions can be formed within the structure of a single layer of CLC material. Alternatively, two color-band reflection regions can also be formed by attaching two separate layers, each layer having one color band. In either case, there is a top light reflecting portion reflecting one part of the spectrum, and a bottom light reflecting portion reflecting a different part of the spectrum to realize the spectral filter structure at hand.

In Fig. 10, an alternative embodiment of the spectral filter structure is provided, wherein a reflective-type "white or silver" matrix is realized by adding a stacked portion 135 having reflective blocking portions for the red-green color band in block 143 and for green-blue color band in block 142, thus providing broad-band reflection over the intersubpixel regions defined thereby, as shown in Fig. 10. Notably, the filter structure of Fig. 10 has five portions stacked in its LC layer, in contrast to the filter structure of Fig. 14 which has four portions stacked in its LC layer.

The single layer embodiments of Figs. 10 and 14 are useful since an entire device is all realized in a single LC layer. With this technique, no peeling, gluing, aligning, steps are needed to make the display device. With fewer layers, the LCD panel can be made thinner, lighter, and have fewer index of reflection problems between layers as there are fewer optical interfaces therewithin.

Fig. 25 shows an embodiment of Fig. 5B1 in which both left-handed CLC layers 40 and 50 are combined with right-handed layers 45 and 55. In this embodiment both polarized and/or unpolarized white light 201, which is composed of right-handed and left-handed circularly polarized light, can be transmitted as red-green, or blue unpolarized light since layers 45 and 55 transmit the right-handed portion of the blue-green, and red light and layers 40 and 50 transmit the left-handed portion of the blue-green, and red light. Layers 40, 45, 50 and 55 can be placed in any order in the stack without effecting the transmitted light. Also as described herein the layers 40, 45, 50 and 55 of cholesteric liquid crystal material can be on one layer or two layers instead of on 4 layers of cholesteric liquid crystal material. Since this polarizer is insensitive to the incident polarization, it can also work with linear polarized light. In this case no quarter-wave plate is required. Due to the symmetric arrangement between the left-handed layer pair (40, and 50) and right-handed layer pair (45, and 55), the optical rotation by the left-handed and right-handed CLC color filters are automatically cancelled provided that the two pairs have the same parameters, such as reflection wavelength, refractive index, birefringence, and film thickness. Therefore, when a linear light is incident on to the CLC color filter, the output light from different color pixel is still linearly polarized in the same polarization plane.

Fig. 11 shows a second embodiment of the invention having two color sections per layer. In this embodiment, reflective cholesteric liquid crystals having a broad band spanning two primary colors are used. Such reflective cholesteric liquid crystals are also made by the method as shown in the description of Fig. 5B1 with the cholesteric liquid crystals of International Application PCT/US96/17464 published by WIPO on May 9, 1997 as WO 97/16762, International Application PCT/US96/14264 published by WIPO on January 21, 1999 as WO 99/02346 and International Application No. PCT/US98/03688 on September 3, 1998 as WO 98/38547. Using the CLC film fabrication method described above, the blue and green portion of the spectrum can be reflected by a first layer of broadband cholesteric liquid crystal film material. Using the CLC film fabrication method described above, the green and red portion of the spectrum can be reflected by a second layer of broadband cholesteric liquid crystal film material. Using these broadband cholesteric liquid crystals, the reflective cholesteric liquid crystal color filters of Figs. 11, 13, 14, 39, 41, and 15 through 26D are made possible. In these embodiments, the top reflective portion and bottom reflective portion may be realized on one layer of material or on two layers as described above.

Returning to the spectral filter structure shown in Fig. 11, when circularly polarized white light 120 is incident on layer 60 on the red (R) reflecting portion, red light is reflected while green and blue light are transmitted; while in layer 70, the blue (B) component of incident light is reflected and green (G) component is transmitted. In the adjacent section G,R of layer 60 both green and red light are reflected as shown in the broadband cholesteric liquid crystal material described above. This section uses the broadband Cholesteric Liquid Crystal material taught in International Application PCT/US96/17464 published by WIPO on May 9, 1997 as WO 97/16762, International Application PCT/US96/14264 published by WIPO on January 21, 1999 as WO 99/02346 and International Application No. PCT/US98/03688 on September 3, 1998 as WO 98/385477, incorporated herein by reference, to obtain the broad band reflectivity needed. Since the green and red spatial components colors are reflected, blue light is transmitted. The top layer in layer 70 does not have to reflect any colors of light. It is therefore made from the same material but in an isotropic state. Or it can be made to reflect light in the infrared or ultraviolet bands and transmit visible light. Similarly in the red (R) transmitting section, layer 60 is clear and layer 70 reflects both green (G) and blue (B) components of light while transmitting red (R) components thereof.

The spectral filter design shown in Fig. 11 has an advantage of being able to make a white (broad-band) reflective matrix integrated within the spectral filter in order to improve

contrast. For example, by extending the green-red (G,R) section of layer 60 under the blue-green B,G section of layer 70 and under the blue (B) section of layer 70, all the colors are reflected from the overlapping portion, thus reflecting white light and transmitting nothing through the filter structures so that the overlapping portion appears "black", from the viewing direction as shown in Fig. 11A. Similarly, the red (R) pixel region in layer 60 is extended under the blue-green (B,G) pixel region in layer 70, and thus a totally reflective black matrix is created at the overlapped portion. Using this architecture, a black matrix is produced, as shown in Fig. 11A.

Fig. 26 shows another stack of layers for producing colored light from both polarized and/or unpolarized white light 201, similar to the stack in Fig. 25 described above. The stack in Fig. 26 has left-handed cholesteric liquid crystals in layers 60 and 70, and right-handed cholesteric liquid crystals in layer 65 and 75. Although Fig. 26 shows the stack producing a black matrix, it is understood from the teaching employed to make the spectral filter structures of Figs. 11 and 13, that the stack in Fig. 26 can be modified so as to produce colored light with or without a black matrix for all the incident polarizations.

Fig. 12A shows a method of making a reflective filter display 130 having two layers. The first layer is a top layer 115 having three subpixels; a subpixel 113 for reflecting blue-green light, a subpixel 117 for reflecting blue light and a clear isotropic subpixel 114. The second layer is a bottom layer 125 having three subpixels: a subpixel 121 for reflecting red-green light, a subpixel 127 for reflecting red light and a clear isotropic subpixel 124 for transmitting all components of incident light.

To make a left-handed reflective cholesteric liquid crystal (CLC) color filter layer 115 reflecting blue-green light in subpixel region 113, blue light in subpixel region 117 and transmitting all components over a clear subpixel region 113, the method first involves preparing a bottom substrate 110 of PVA (polyvinyl alcohol) coated glass, by buffing it in one direction. Then, prepare a top substrate 112 of PET (Mylar D) by buffing it in any direction.

The next step of the process involves mixing a left-handed CLC polymer comprising blue polysiloxane, such as that sold by Wacker Chemical Company of Germany as SLM 90032, 47.5% by weight, a left-handed CLC polymer comprising blue polysiloxane, such as that sold by Wacker Chemical Company of Germany as SLM 90031, 19.1% by weight, and with a low molecular weight nematic liquid crystal, such as that sold by EMI Company of Germany as (E44, EMI): 32.1% by weight. Then add a chiral dopant such as (S1011) sold by EMI and photo initiator (IG184) sold by Ciba-Geigy of U.S.A., 0.35% of the polymers,

are added to the mixture. The above materials should be mixed at 120° C and de-gassed in a vacuum for 20 minutes at 90°C.

The mixture is then coated onto the PVA coated glass bottom substrate 110 using a knife coater. The coating is preferably about 8-12 microns thick. The coating temperature and the gap of the knife coater can be used to vary the thickness of the coating as applied.

The mixture is then laminated with the PET top substrate 112 using a laminator. The temperature and the gap between the rollers of the laminator will effect the final thickness of the film.

The layer 115 is then heated at 75° C with the PET substrate 112 facing up. The heating is preferably done on a hot plate.

With the layer 115 at 75° C, it is preferably mechanically sheared to align the liquid crystal molecules. Mechanical shearing provides a tangential mechanical force which helps align the liquid crystal molecules between substrates 110 and 112 in layer 115.

With layer 115 still on the hot plate or still heated to 75° C, a mask is applied to the top substrate layer 112 having the PET material. The mask will vary in size and shape depending on the use of the layer. For use in color displays the mask will be the size and shape of pixels used in the display. In the layer shown in Fig. 3, the display uses two layers with three subpixels, two being reflective color filter portions per layer.

A mask is then applied to block the subpixel regions in the layer 115 at which blue-green subpixel region 113 and clear subpixel region 114 are to be formed, leaving the blue subpixel 117 exposed.

While maintained at 75° C, layer 115 is then exposed to UV light of 360nm at 0.1 mW/cm<sup>2</sup> intensity for approximately 20 seconds to polymerize the exposed cholesteric liquid crystals in the blue subpixel region 117 of layer 115.

While at 75° C layer, layer 115 is further exposed at 75°C with a collimated UV of about 360nm at another intensity of about 10mW/cm<sup>2</sup> for about 30 seconds.

While maintained at 75° C, the mask blocking the blue-green subpixel region 117 is removed and layer 115 is exposed to UV light 360nm at 0.1 mW/cm<sup>2</sup> for approximately 40 seconds to polymerize the blue-green subpixel 113 of layer 115 with the desired bandwidth.

While maintained at 75° C, layer 115 is further exposed at 75°C with a collimated UV of about 360nm at another intensity of about 10mW/cm<sup>2</sup> for about 30 seconds.

The mask is then totally removed exposing all of layer 115.

The temperature is raised to 150° C to polymerize the clear isotropic phase subpixel region 114.

While maintained at 150° C the layer 115 is then exposed to UV light of 360 nm at 20 mW/cm<sup>2</sup> for approximately 30 seconds to set the polymers.

The PET substrate 112 is then removed. Layer 115 is now ready for installation in a display or for other use.

To make the left-handed reflective cholesteric liquid crystal (CLC) color filter layer 125 for reflecting red-green broadband light in subpixel region 121, red light in subpixel region 127 and all spectral components in a clear isotropic subpixel region 124, the method then involves preparing a bottom substrate 120 of PVA (polyvinyl alcohol) coated glass, by buffing it in one direction. Then, prepare a top substrate 122 of PET (Mylar D) by buffing it in any direction.

The next step of the method involves mixing a left-handed CLC polymer comprising blue polysiloxane, such as that sold by Wacker Chemical Company of Germany as SLM 90032, 63% by weight, with a low molecular weight nematic liquid crystal, such as that sold by EMI Company of Germany as (E44, EMI): 28.6% by weight. Then a low molecular nematic liquid crystal such as (TEB30) sold by SLICHEM of China, 8.4% by weight, and photo-initiator (IG184, Ciba-Geigy), 0.35% of the liquid crystal polymer, are added to the mixture. The above materials are mixed at 120° C and de-gassed in a vacuum for 20 minutes at 90°C.

The mixture is then coated onto the PVA coated glass bottom substrate 120 using a knife coater. The coating is preferably about 8-12 microns thick. The coating temperature and the gap of the knife coater can be used to vary the thickness of the coating as applied.

The mixture is then laminated with the PET top substrate 122 using a laminator. The temperature and the gap between the rollers of the laminator will effect the final thickness of the film.

To make a CLC film having red-green subpixel region 121, red subpixel region 127 and clear subpixel 124 in layer 125, layer 125 is heated at 75° C with the PET substrate 122 facing up. The heating is preferably done on a hot plate.

While layer 125 is maintained at 75° C, it is preferably mechanically sheared to align the liquid crystal molecules. Mechanical shearing provides a tangential mechanical force which helps align the liquid crystal molecules between substrates 120 and 122 in layer 125.

With layer 125 still on the hot plate or still heated to 75° C, a mask is applied to the top substrate layer 122 having the PET material. The mask is applied to block the subpixel region of the layer 125 to the red-green subpixel region 121 and clear subpixel region 124 leaving the red subpixel region 127 exposed.



While maintained at 75° C layer 125 is then exposed to UV light of 360 nm at 0.1 mW/cm<sup>2</sup> intensity for approximately 20 seconds to polymerize the exposed cholesteric liquid crystals in the red subpixel region 127 of layer 125.

While maintained at 75° C, layer 125 is further exposed by a collimated UV of about 360nm at another intensity of about 10mW/cm<sup>2</sup> for about 30 seconds.

While maintained at 75° C, the mask blocking the red-green subpixel 121 is moved and layer 125 is exposed to UV light 360nm at 0.1 mW/cm<sup>2</sup> for approximately 40 seconds to polymerize the red-green subpixel 121 of layer 125 with the desired bandwidth.

While still at 75° C layer, 125 is further exposed by a collimated UV of about 360nm at another intensity of about 10mW/cm<sup>2</sup> for about 30 seconds.

The mask is then totally removed exposing all of layer 125.

The temperature is raised to 150° C to polymerize the clear isotropic phase region 124.

Maintained at 150° C, layer 125 is then exposed to UV light of 360 nm at 20 mW/cm<sup>2</sup> for approximately 30 seconds to set the polymers

The PET substrate is then removed. Layer 125 is now ready for installation in a display or for other usage.

As shown in Fig. 12A layers 115 and 125 can be installed in a display device by using, for example, UV curable adhesives as applied with the layers 15 and 25 in the device of Fig. 2.

Similarly, as shown in Fig. 27 right-handed and left-handed layers 30, 20 and 35, 25 from Fig. 5B1 can also be used to produce colored light from both polarized and/or unpolarized white light sources 201.

Fig. 15 shows another embodiment of the method for patterning the color filter in each layer associated with the spectral filter Figs. 11 and 13. Instead of patterning "green-blue", "clear", and "blue" ("B,G", "clear", "B") as in layer 70 of Fig. 13, it can be patterned into "Clear", "B", "B", "Clear", "G,B", "G,B", "Clear". Similarly, layer 60 can be patterned to be "R,G", "R", "R", "R,G", "Clear", "Clear", "R,G", "R", "R", where "R", "G" and "B" refer to the filter layer portion reflecting blue and red light, respectively and Clr refers to a clear portion of the layer transmitting all spectral components over the visible band. If the two layers are aligned in the way as shown in Fig. 15, color filter pixels consisting of subpixels (R<sub>i</sub>, B<sub>i</sub>, G<sub>i</sub>) and (G<sub>i</sub>, B<sub>i</sub>, R<sub>i</sub>) will be formed, where "R<sub>i</sub>", "G<sub>i</sub>", and "B<sub>i</sub>" refer to the red-green, and blue subpixels in transmission. In this manner, the blue B, green-blue G,B, red(R) and clear Clr subpixels are doubled up such that one large subpixel takes the place of two smaller ones providing an easier fabrication process. Using the same scheme as taught in

Fig. 14, a black matrix will be automatically formed in this color filter structure when overlapping reflective portions reflecting all colors are used.

Pixels in a display having three subpixels, one subpixel for each of the primary colors of red-green, and blue are shown above in Fig. 5B1.

Pixels in a display may also have four subpixels, one subpixel for each of the primary colors red-green, and blue and one for transmitting white light, shown as a clear subpixel region in spectral filter structures of Figs. 16A through 24A. Again, the clear pixel region can be made from the same material in a clear isotropic state or, this clear subpixel can be made to reflect light in the infrared or ultraviolet bands and transmit the visible light.

As shown above in Fig. 15, for three subpixel type arrays of pixels made up of two layers of reflective color filter material, the subpixels can be arranged to make two or more adjacent subpixels in a layer the same color for ease of manufacture. Subpixels of one color can then be made 2 times or even 4 times as large as one subpixel.

With four subpixels per pixel, the number of combinations of subpixel patterns is much larger than with three subpixels. The object is to find combinations for the two layers of reflective color filter material making up the spectral filter arrays having the largest possible number of adjacent subpixels with the same color for ease of manufacturing the displays in which the spectral filter structures are incorporated.

The pixels in the four subpixel display will have 24 combinations of subpixels per pixel. If the pixel sizes are small enough, then the human eye will not be able to detect that the subpixels are in different places for adjacent pixels. Therefore, pixels which are mirror images of each other may be used where the subpixels will then have adjacent colors, for ease of manufacture.

In Fig. 16A, a two-layer color filter system is shown. Fig 16B is the top layer, Fig. 16C is the bottom layer and Fig. 16D is the transmissive color pixel pattern. In the figure, "GR" means that the pixel reflects in green and red; "GB" means that the pixel reflects in green and blue; "B" means that the pixel reflects in blue; "R" means that the pixel reflects in red, and "Clr" means that the pixel is transparent in the visible. However, it can reflect infrared and/or ultraviolet light. When the two layers are aligned and laminated to each other, a color filter is generated with a transmission color configuration as shown in Fig. 16C.

In the pixel pattern of Fig. 16B, the top layer of the highlighted pixel has a pixel array wherein the subpixel pattern in the top row has from left to right green-blue GB and blue(B) the bottom row has green-red GR and Clear Clr. The pattern repeats throughout the array. The bottom layer of Fig. 16C has a pixel array, wherein the subpixel pattern in the

top row has from left to right clear Clr and red the bottom row has clear Clr and clear Clr. This pattern results in a pixel Fig 16D having a top row from left to right transmitting red and green(G) and a bottom row transmitting blue(B) and clear (clr). The array has pixels which are all the same. However the pattern in the top layer has no adjacent colors which are the same making the array more difficult to make. The bottom layer has an array with mostly clear Clr subpixels but the red(R) subpixels are never adjacent making it more difficult to make the red(R) subpixels.

To make the pixel arrays easier to manufacture, Fig. 17A shows the pixel array of Fig. 16A with rows 1 and 2 reversed in the top layer and the bottom layer. The top layer now has in rows 2 and 3 a green-red GR subpixel adjacent a green-red GR subpixel and a clear Clr subpixel adjacent a clear Clr subpixel. Similarly with the array extended beyond what is shown it is easy to see that a green-blue GB subpixel and a blue subpixel will also be adjacent. This doubles the size of the subpixels and makes the top layer easier to manufacture. The pattern on the bottom layer is also easier to manufacture because rows 2 and 3 are all clear Clr making 8 subpixels adjacent with the same color. However as shown in Fig. 17D the transmissive color pixel has a top pixel with a mirror image of the bottom pixel. When the pixel sizes are small the human eye will not be able to tell that the pixels are different and the images shown will not be distorted by the different subpixel patterns in the adjacent pixels.

To further enlarge the subpixel sizes, the arrows in Fig 18B for the top layer show the top left clear Clr and bottom right green-blue GB subpixels exchanging positions and the bottom left and top right subpixels exchanging positions. As shown in Fig. 18D the array, by extension, has in the top row with two adjacent clear Clr subpixels then two adjacent green-red GR subpixels, then two adjacent clear Clr subpixels again etc. The second row has two blue(B) subpixels then two green-blue GB subpixels etc. Similarly, the third and fourth rows also always have two adjacent subpixels of the same color. The subpixels can now all be twice the size when manufactured making the top layer easier to manufacture. In terms of manufacture, the bottom layer in Fig 18 has the same complexity as the bottom layer in Fig. 17C, with two adjacent columns of clear Clr subpixels present instead of two adjacent rows. Fig. 17D shows that all the adjacent columns of pixels will be mirror images of each other. If the pixels are small enough the human eye will not see any distortion of the images displayed by this difference in pixels.

As the arrows in Fig. 17 show the top two rows from Fig. 16 can be exchanged in the top and bottom layers. The top layer Fig 18B now shows groups of four adjacent subpixels for green-red GR, clear Clr, green-blue GB and blue(B) in a pixel array. Since the

manufactured subpixel sizes are now four times the size of one subpixel it is much easier to make the top layer. The bottom layer Fig. 19C shows that the second and third rows and the second and third columns are all clear subpixels making it easy to make and the array will have squares of four adjacent red subpixels for ease of manufacture of the bottom layer.

The transmissive array of pixels will have subpixels as shown in Fig. 19D with each adjacent subpixel being different and the mirror image of the adjacent pixel either diagonally, top to bottom or left to right. With sufficiently small pixel sizes the human eye will not be able to tell each adjacent pixel has a different subpixel arrangement.

Fig. 20 shows a new pixel array wherein each pixel has a top layer with green-red GR, Clear Clr, green(G) and blue(B) a bottom layer with, Clear Clr, Clear Clr, blue(B) subpixel region and red(R) in the positions as shown in Fig. 20B and Fig. 20C, respectively. The resulting transmitted light is as shown in Fig. 20D having blue B, clear Clr, red(R) and green(G) subpixels.

Fig. 21A shows an equivalent pixel array to the one shown in Fig 20A. However, in the subpixels for transmitting red light instead of using a green(G) subpixel in the top layer and a blue(B) in the bottom layer of Fig. 20, a clear Clr subpixel is used in the top layer and a green-blue GB subpixel is used in the bottom layer. This now provides two clear Clr subpixels in the top layer pixels which can be rearranged in patterns of adjacent clear portions for ease of manufacture.

Fig. 22D shows the same resultant pixel as Fig 21D. However, the top layer subpixels shown in Fig 22B, and the bottom layer subpixels shown in Fig. 24B have been altered to show that the same results are obtained (1) by changing a subpixel, such as clear Clr in the top layer with the green-blue GB layer in the bottom layer, and, also, (2) by changing the green-red GR in the top layer to green(G) while changing the corresponding bottom layer subpixel from Clear Clr to red R.

The subpixel arrangement shown in Figs. 23B and 23C are the equivalents of the subpixel arrangements shown in Figs. 22B and 22C, as the transmitted light pattern shown in Fig. 22D and Fig. 23D are identically the same. The only difference is that the green-blue GB subpixel region of Fig 22B paired with the clear Clr subpixel region of Fig. 22C, has been replaced with the equivalent pair of the green(G) subpixel of Fig. 23B and the blue(B) subpixel of Fig 23C. This substitution yields a column of green subpixels in the top layer as shown in Fig. 23B which is easier to manufacture.

Similarly, combining the green subpixel top layer of Fig. 23B and blue subpixel Fig. 23C to form the clear (Clr) subpixel of the top layer of Fig 24B and the green-blue GB subpixel of Fig. 24C forms top layer 24B and bottom layer 24C with a pattern that can be

rearranged to form rows and columns with the same color subpixels for ease of manufacturing.

As illustrated above, by switching patterns in just the top and bottom layers and between the top and bottom layers, different patterns of pixels and subpixels can be formed. Combinations with adjacent subpixels of the same color in each layer are preferred for ease of manufacture.

Fig. 28 shows yet another embodiment of the spectral filter structure of the present invention, in which the stack of reflective filter layers shown in Fig. 5B1 is repeated with opposite-handedness cholesteric liquid crystals to form a four layer stack, capable of transmitting any polarized light component having the correct color characteristics. Portion 100R is formed from right-handed cholesteric liquid crystal material and portion 100L is formed from left-handed cholesteric liquid crystal material. The stack is made by polymerizing portion 15L, 15R, 25L and 25R in separate steps to form the four portion stack in single layer of CLC material 105.

The polymerizable cholesteric liquid crystal materials used to make the reflective materials described above can be mixtures of polymerizable and non-polymerizable components. The polymerizable components may be monomers, oligomers, nematics, or active chiral additives. The non-polymerizable components may have a pitch distribution which is non linear, resulting in a broad-band of reflection wavelengths in the reflective cholesteric liquid crystal color filters produced. Preferably, the non-polymerizable liquid crystal component is phase segregated from the polymerizable liquid crystal and diffuses along the UV field to generate a pitch gradient. The bandwidth is adjusted by the diffusion rate of the non-polarizable liquid crystal component being slower than the polymerization rate of the polymerizable liquid crystal.

#### Second Illustrative Embodiment Of The Generalized LCD Panel Construction Shown In Fig. 2

In the illustrative embodiments shown in Figs. 29 through 30F, the backlighting structure 7 is realized in a manner described above. Understandably, there are other techniques for producing a plane of unpolarized light for use in connection with the LCD panel of the present invention.

In the illustrative embodiment of Fig. 29 through and 30F, the pixelated array of polarization rotating elements 9 is realized as an array of linear polarization rotating elements 9' formed within a single plane. As indicated in Figs. 30A1 and 30A2, each pass-

band linear polarizing reflective element 10A', 10B', 10C' in the pixelated pass-band linearly polarizing panel 10' has a LP2 characteristic polarization state, whereas the broad-band linear polarizing reflective panel 8' adjacent the backlighting structure has an LP1 characteristic polarization state and the broad-band linearly polarizing reflective panel 11' has an LP2 characteristic polarization state.

A method of making the broad-band linearly polarizing reflective panels 8' and 11' is disclosed in great detail in International Application Number PCT/US96/17464 entitled "Super Broad-band Polarizing Reflective Material" published on May 9, 1997 under International Publication Number WO 97/16762, which is incorporated herein by reference in its entirety. The reflection characteristics of the broad-band linearly polarizing reflective panel 8' are graphically illustrated in Fig. 30B for incident light having linear polarization state LP1, whereas the reflection characteristics of the broad-band linearly polarizing reflective panel 11' are graphically illustrated in Fig. 30C for incident light having linear polarization state LP2.

In the illustrative embodiment of Figs. 30A1 and 30A2, the polarization rotating array 9 is realized as an array of electronically-controlled linear polarization rotating elements 9A', 9B', 9C' for rotating the linearly polarized electric field along LP1 to the LP2 polarization direction as the light rays are transmitted through the spatially corresponding pixels in the LCD panel. In the illustrative embodiment of Figs. 30A1 and 30A2, each electronically-controlled linear polarization rotating element can be realized as a twisted nematic (TN) liquid crystal cell, super-twisted nematic (STN) liquid crystal cell, or ferro-electric cell, whose operation is by controlled by a control voltage well known in the art. To construct the linear polarization rotating elements, thin film transistors (TFTs) can be used to create the necessary voltages across a layer of liquid crystal material to achieve alignment of the liquid crystal molecules and thus cause the corresponding element to not rotate the polarization direction of transmitted light passing therethrough. In its electrically-inactive state (i.e. no voltage is applied), the electric field intensity of light exiting from the cell is substantially zero and thus a "dark" subpixel level is produced. In its electrically-active state (i.e. the threshold voltage  $V_T$  is applied), the electric field intensity of light exiting from the cell is substantially non-zero and thus a "bright" subpixel level is produced.

In the illustrative embodiment of Fig. 30A1 and 30A2, the pixelated array of spectral filtering elements (i.e. spectral filter structures) 10 is realized as an array of pass-band linear polarizing reflective elements 10A', 10B', 10C' formed within a single plane. Broad-band linearly polarizing reflective panel 11' is laminated to the pixelated array of spectral filtering elements 10.

As shown in Fig. 30D, each pass-band polarizing reflective element 10C' associated with a "blue" subpixel in the pixelated pass-band linear polarizing panel 10' is particularly designed to reflect nearly 100% all spectral components having the LP2 characteristic polarization state and a wavelength within the green reflective band  $\Delta\lambda_G$  or the red reflective band  $\Delta\lambda_R$ , whereas all spectral components having the LP2 characteristic polarization state and a wavelength within the blue reflective band  $\Delta\lambda_B$  are transmitted nearly 100% through the pass-band polarizing reflective element. The pass-band polarizing reflective element associated with each "blue" subpixel is "tuned" during fabrication in the manner described hereinabove.

As shown in Fig. 30E, each pass-band polarizing reflective element 10B' associated with a "green" subpixel in the pixelated pass-band linearly polarizing panel 10' is particularly designed to reflect nearly 100% all spectral components having the LP2 characteristic polarization state and a wavelength within the red reflective band  $\Delta\lambda_R$  or the blue reflective band  $\Delta\lambda_B$ , whereas all spectral components having the LP2 characteristic polarization state and a wavelength within the green reflective band  $\Delta\lambda_G$  are transmitted nearly 100% through the pass-band polarizing reflective element. The pass-band polarizing reflective element associated with each "green" subpixel is "tuned" during fabrication in the manner described hereinabove.

As shown in Fig. 30F, each pass-band polarizing reflective element 10C' associated with a "red" subpixel in the pixelated pass-band linear polarizing panel 10' is particularly designed to reflect nearly 100% all spectral components having the LP2 characteristic polarization state and a wavelength within the green reflective band  $\Delta\lambda_G$  or the blue reflective band, whereas all spectral components having the LP2 characteristic polarization state and a wavelength within the red reflective band  $\Delta\lambda_R$  are transmitted nearly 100% through the pass-band polarizing reflective element. The pass-band polarizing reflective element associated with each "red" subpixel is "tuned" during fabrication in the manner described hereinabove.

The pixelated pass-band linearly polarizing reflective panel 9' can be fabricated in a manner similar to the way described in the LCD panel fabrication method described hereinabove.

The Second Generalized LCD Panel Construction Of The Present Invention

In the second generalized LCD panel construction shown in Fig. 31, spectral filtering occurs before spatial intensity modulation. In the first illustrative embodiment of this LCD panel construction shown in Figs. 31A1 and 31A2, circular polarization techniques are used to carry out the spatial intensity modulation and spectral filtering functions employed therein. In the second illustrative embodiment of this LCD panel construction shown in Figs. 32A1 and 32A2, linear polarization techniques are used to carry out the spatial intensity modulation and spectral filtering functions employed therein. In each such illustrative embodiment, modifications are made among the various components of the LCD panel shown in Fig. 31. Details regarding such modifications will be described hereinafter.

In Fig. 31, the subcomponent structure of the second generalized embodiment of the LCD panel hereof is shown in great clarity. As shown, the second generalized embodiment of the LCD panel 2 comprises: a backlighting structure 7 including a quasi-diffusive reflector 7A, for producing a plane of broad-band light having a substantially uniform light intensity over the x and y coordinate axes thereof; a broad-band CLC-based polarizing reflective panel 8; a light condensing film layer 410 applied to the broad-band polarizing reflective panel 8; pixelated array 10 of pass-band polarizing reflective (filter) elements 10A, 10B, 10C, for spectral filtering of light produced from the backlighting structure; a pixelated array 9 of polarization direction rotating elements 9A, 9B, 9C for spatial intensity modulation of light produced from the pixelated array of pass-band polarizing reflective (filter) elements; a broad-band polarizing reflective panel 11 for cooperative operation with the pixelated array of polarization direction rotating elements 9 and the pixelated array of pass-band polarizing reflective (filter) elements 10; and a polarization-preserving light diffusive film layer 420 applied to the broad-band reflective polarizing panel 11 to improve the angular viewing performance of the LCD panel assembly. In an alternative embodiment, a broad-band absorptive-type panel can be substituted for broad-band polarizing reflective panel 11 in order to reduce glare due to ambient light incident upon the LCD panel during operation.

In order to produce high-resolution color images, the spatial period of the pixelated arrays 9 and 10 is selected to be relatively small in relation to the overall length and height dimensions of the LCD panel. In a conventional manner, each pixel structure in the LCD panel is comprised of a red subpixel 13A, a green subpixel 13B and blue subpixel 13C. As shown therein, each red subpixel structure 13A comprises a red-band spectral filtering element 10A which is spatially registered with a first polarization direction rotating element



9A. Each green subpixel structure 13B comprises a green-band spectral filtering element 10B spatially registered with a second polarization direction rotating element 9B. Each blue subpixel element 13C comprises a blue-band spectral filtering element 10C spatially registered with a third polarization direction rotating element 9C. The output intensity (i.e. brightness or darkness level) of each red subpixel structure is controlled by applying pulse-width modulated voltage signal  $V_R$  to the electrodes of its electrically-controlled spatially intensity modulating element. The output intensity of each green subpixel structure is controlled by applying pulse-width modulated voltage signal  $V_G$  to the electrodes of its electrically-controlled spatially intensity modulating element. The output intensity of each blue subpixel structure is controlled by providing pulse-width modulated voltage signal  $V_B$  applied to the electrodes of its electrically-controlled spatially intensity modulating element. By simply controlling the width of the above-described voltages  $V_R$ ,  $V_G$ ,  $V_B$ , the grey-scale intensity (i.e. brightness) level of each subpixel structure can be controlled in a manner well known in the LCD panel art.

In Figs. 31A1 through 31F, a circularly polarizing embodiment of the system shown in Fig. 31 is shown in detail, along with a schematic of its operation during the generation of bright and dark subpixel structures.

In Figs. 32A1 through 32F, a linearly polarizing embodiment of the system shown in Fig. 31 is shown in detail, along with a schematic of its operation during the generation of bright and dark subpixel structures.

#### Modifications To The Four Basic LCD System Designs To Reduce Glare From Ambient Light And Improve Image Contrast

As shown in Fig. 33, the LCD panel of Figs. 3A1 and 3A2 is shown modified by mounting a first broad-band absorptive circular polarizer panel 8A'' to the front surface of broad-band circularly polarizing reflective panel 8'', and mounting a second broad-band absorptive circular polarizer panel 11A'' to the front surface of broad-band circularly polarizing reflective panel 11''. The polarization state of broad-band absorptive circular polarizer panel 8A'' is LHCP in order to match the LHCP polarization state of broad-band circularly polarizing reflective panel 8''. Such polarization matching ensures that spectral energy which is not reflected from the broad-band polarizing reflective panel 8'', but is transmitted (i.e. leaked) therethrough due to a suboptimal extinction ratio, is absorbed by the broad-band absorptive circular polarizer panel 8A'' through energy dissipation. Similarly, the polarization state of broad-band absorptive circular polarizer panel 11A'' is

RHCP in order to match the RHCP polarization state of broad-band polarizing reflective panel 11". Such polarization matching ensures that spectral energy which is not reflected from the broad-band polarizing reflective panel 11", but is transmitted (i.e. leaked) therethrough due to a suboptimal extinction ratio, is absorbed by the broad-band absorptive circular polarizer panel 11A" through energy dissipation. Preferably, these absorptive circularly polarizing filter panels 8A" and 11A" are laminated directly onto broad-band circularly polarizing reflective panels 8" and 11", respectively. The use of broad-band absorptive circular polarizers 8A" and 11A" substantially improves the contrast of images formed by the LCD panel, without reducing the light transmission efficiency along the light projection axis of the LCD panel. Such broad-band absorptive polarizers can be realized using dichroic polarizing material well known in the art.

As shown in Fig. 34, the LCD panel of Figs. 30A1 and 30A2 is shown modified by mounting a first broad-band absorptive linear polarizer 8A' to the front surface of broad-band linearly polarizing reflective panel 8', and mounting a second broad-band absorptive linear polarizer panel 11A' to the front surface of broad-band linearly polarizing reflective panel 11'. The polarization state of broad-band absorptive linear polarizer panel 8A' is LP1 in order to match the LP1 polarization state of broad-band linearly polarizing reflective panel 8'. Such polarization matching ensures that spectral energy which is not reflected from the broad-band linearly polarizing reflective panel 8', but is transmitted (i.e. leaked) therethrough due to a suboptimal extinction ratio, is absorbed by the broad-band absorptive linear polarizer panel 8A' through energy dissipation. Similarly, the polarization state of broad-band absorptive linear polarizer panel 11A' is LP2 in order to match the LP2 polarization state of broad-band linearly polarizing reflective panel 11'. Such polarization matching ensures that spectral energy which is not reflected from the broad-band polarizing reflective panel 11', but is transmitted (i.e. leaked) therethrough due to a suboptimal extinction ratio, is absorbed by the broad-band absorptive linear polarizer 11A' through energy dissipation. Preferably, these absorptive polarizing filter panels 8A' and 11A' are laminated directly onto broad-band linearly polarizing reflective panels 8 and 11, respectively. The use of broad-band absorptive linear polarizers 8A' and 8A" substantially improves the contrast of images formed by the LCD panel, without reducing the light transmission efficiency along the light projection axis of the LCD panel. Such broad-band absorptive polarizers can be realized using dichroic polarizing material well known in the art.

As shown in Fig. 35, the LCD panel of Figs. 31A1 and 31A2 can be modified by mounting a first broad-band absorptive circular polarizer 8A" to the front surface of broad-

band circularly polarizing reflective panel 8'', and mounting a second broad-band absorptive circular polarizer panel 11A'' to the front surface of broad-band circularly polarizing reflective panel 11''. The polarization state of broad-band absorptive circular polarizer panel 8A'' is LHCP in order to match the LHCP polarization state of broad-band circularly polarizing reflective panel 8''. Such polarization matching ensures that spectral energy which is not reflected from the broad-band circularly polarizing reflective panel 8'', but is transmitted (i.e. leaked) therethrough due to a suboptimal extinction ratio, is absorbed by the broad-band absorptive circular polarizer 8A'' through energy dissipation. Similarly, the polarization state of broad-band absorptive circular polarizer panel 11A'' is RHCP in order to match the RHCP polarization state of broad-band circularly polarizing reflective panel 11''. Such polarization matching ensures that spectral energy which is not reflected from the broad-band polarizing reflective panel 11'', but is transmitted (i.e. leaked) therethrough due to a suboptimal extinction ratio, is absorbed by the broad-band absorptive circular polarizer panel 11A'' through energy dissipation. The use of broad-band absorptive circular polarizers 8A'' and 11A'' substantially improves the contrast of images formed by the LCD panel, without reducing the light transmission efficiency along the light projection axis of the LCD panel. Such broad-band absorptive polarizers can be realized using dichroic polarizing material well known in the art. Preferably, these absorptive circularly polarizing filter panels 8A'' and 11A'' are laminated directly onto broad-band circularly polarizing reflective panels 8'' and 11'', respectively, during the fabrication process of the LCD panel.

As shown in Fig. 36, the LCD panel of Figs. 32A1 and 32A2 can be modified by mounting a first broad-band absorptive linear polarizer 8A' to the front surface of broad-band polarizing reflective panel 8', and mounting a second broad-band absorptive linear polarizer 11A' to the front surface of broad-band polarizing reflective panel 11'. The polarization state of broad-band absorptive linear polarizer panel 8' is LP1 in order to match the LP1 polarization state of broad-band linearly polarizing reflective panel 8'. Such polarization matching ensures that spectral energy which is not reflected from the broad-band polarizing reflective panel 8', but is transmitted (i.e. leaked) therethrough due to a suboptimal extinction ratio, is absorbed by the broad-band absorptive linear polarizer 8A' through energy dissipation. Similarly, the polarization state of broad-band absorptive linear polarizer 11A' is LP1 in order to match the LP1 polarization state of broad-band polarizing reflective panel 11'. Such polarization matching ensures that spectral energy which is not reflected from the broad-band linearly polarizing reflective panel 11', but is transmitted (i.e. leaked) therethrough due to a suboptimal extinction ratio, is absorbed by the broad-band absorptive linear polarizer 11A' through energy dissipation. The use of broad-band

absorptive linear polarizers 8A' and 11A' substantially improves the contrast of images formed by the LCD panel, without reducing the light transmission efficiency along the light projection axis of the LCD panel which, as shown in Fig. 2, extends from the backlighting structure towards the eyes of the viewer. Such broad-band absorptive polarizers can be realized using dichroic polarizing material well known in the art. Preferably, these absorptive polarizing filter panels 8A' and 11A' are laminated directly onto broad-band linearly polarizing reflective panels 8' and 11', respectively, during the fabrication process of the LCD panel.

As shown in Fig. 37A, the LCD panel of the present invention is shown as part of a direct-view type color image display system 1 which is capable of supporting displaying high-resolution color images. During operation, the LCD panel 2 is actively driven by pixel driver circuitry 3 in response to color image data sets produced from a host system 4 which can be a computer-graphics board (subsystem), a video source (e.g. VCR), camera, or like system. The function of the LCD panel 2 is to spatial intensity modulate and spectrally filter on a subpixel basis the light emitted from an edge-illuminated backlighting structure 2A which may be realized in a variety of ways. The optically processed pattern of light forms color images at the surface of the LCD panel for direct viewing.

As shown in Fig. 37B, the LCD panel of the present invention 2' is shown as part of a projection-view type color image display system 1' which is capable of supporting displaying high-resolution color images. During operation, the LCD panel 2' is actively driven by pixel driver circuitry 3 in response to color image data sets produced from host system 4 which can be a computer-graphics board (subsystem), a video source (e.g. VCR), camera, or like system. The function of light source 5 is to produce and project a beam of light through the entire extent of the LCD panel. The function of the LCD panel is to spatial intensity modulate and spectrally filter the projected light on a subpixel basis. The optically processed pattern of light forms color images at the surface of the LCD panel which are then projected by projection optics 6 onto a remote display surface (e.g. screen or wall) for projection viewing.

The systems shown in Figs. 37A and 37B are each designed to support monoscopic viewing of color images representative of 2-D and/or 3-D geometry. However, these image display systems can be readily adapted to support stereoscopic viewing of 3-D objects and scenery of either a real and/or synthetic nature. One way of providing such viewing capabilities is to mount (i.e. laminate) a micropolarization panel upon the display surface of the LCD panels 2 and 2' in order to display micropolarized spatially multiplexed images (SMIs) of 3-D objects and scenery, for viewing through electrically-passive polarizing

eyeglasses, as disclosed in US Patent No. 5,537,144 and International Application Serial No. PCT/US97/03985, incorporated herein by reference.

In general, there are many applications to which the LCD panels of the present invention can be put. One such application is illustrated in Fig. 38. As shown, the LCD panel hereof can be integrated into a ultra-high brightness color image projection system of transportable design. In this particular embodiment, the image projection system is embodied within a laptop computer system having both direct and projection viewing modes, similar to the systems described in Applicant's: International Application No. PCT/US96/19718; International Application No. PCT/US95/12846; and International Application No. PCT/US95/05133, each incorporated herein by reference in its entirety.

As shown in Fig. 38, portable image projection system 30 comprises a number of subsystem components, namely: a compact housing of transportable construction having a display portion 31A with a frontwardly located display window 32, and a base portion 32B hingedly connected to the display portion 31A and having a keypad 33 and a pointing device 34; an LCD panel 2, 2' according to the present invention described above, mounted within the housing display portion 31A; an ultra-thin projection lens panel 35 (e.g. Fresnel lens, holographic lens, etc.) laminated to the front surface of the LCD panel 2; a backlighting structure 7' of cascaded construction, mounted to the rear of the LCD panel 2 in a conventional manner; associated apparatus, (e.g. pixel driver circuitry, image display buffers, an image display controller, a rechargeable battery power supply, input/output circuitry for receiving video input signals from various types of external sources, microprocessor and associated memory, etc.), contained within the base portion 32B; a projection lens 37 supported by a bracket 38 which can be removed during the direct viewing mode and stored within a compartment 39 formed within the base portion of the housing; and an electro-optically controllable light diffusing panel 40 which does not scatter backprojected light in the projection viewing mode, and scatters back project light in the direct viewing mode.

In the direct-viewing mode of the system of Fig. 38, the projection lens 37 is stored within compartment 39, electro-optically controllable light diffusing panel 40 is switched to its light scattering state, and the backlighting structure produces light which is spatial-intensity modulated and spectrally filtered to produce color images on the surface of the LCD panel 2. In the projection-viewing mode, the projection lens 37 is mounted along the projection axis (optical axis) 41 of the Fresnel lens panel 35, electro-optically controllable light diffusing panel 40 is switched to its light non-scattering state, and the backlighting structure produces light which is spatial-intensity modulated and spectrally filtered to

produce color images on the surface of the LCD panel 2. Projection lens 37 projects the formed color image onto a remote viewing surface 42 for projection viewing. By virtue of the ultra-high light transmission efficiency of the LCD panel 2 hereof, the system of Fig. 38 can project bright color images onto remote surfaces without the use of external high-intensity lighting sources required by prior art LCD projection systems. In portable applications, such images can be projected using the battery power source aboard the transportable system. With this design, there is not need for a rearwardly opening window in the back of display housing portion 31A, required of prior art projection system. When not in use, the system easily folds into a ultra-slim book-like configuration for easy of storage and transportability.

The CLC filter structures described hereinabove can be assembled as optical devices designed for use in various types of LCD panel systems of the improved image brightness and color quality. Several examples of such optical devices are described below.

Fig. 39 shows an embodiment of Fig. 11 where a source of unpolarized white light is directed incident on a right-handed broadband cholesteric liquid crystal panel 115 which transmits left-handed circularly polarized white incident light and reflects right-handed circularly polarized white light. A white matrix is provided by white matrix layer 85 by physically blocking transmission of light into the left-handed reflective color filter layers 60 and 70. After layer 70, red (R) green (G) and blue (B) left-handed circularly polarized light are transmitted as shown above with left-handed cholesteric liquid crystal color filter layers 60 and 70. A quarter-wave plate 80 adjacent reflective cholesteric liquid crystal color filters in layer 70 transforms the transmitted left-handed circularly polarized light into linearly polarized light, which is used in liquid crystal displays, such as those disclosed in International Application PCT/US96/17464 published by WIPO on May 9, 1997 as WO 97/16762, International Application PCT/US96/14264 published by WIPO on January 21, 1999 as WO 99/02346 and International Application No. PCT/US98/03688 on September 3, 1998 as WO 98/38547, each of which is hereby made a part hereof and incorporated herein by reference.

Fig. 40 shows a modification of the spectral filter structure of Fig. 5B1, wherein a source of unpolarized white light is directed incident on a right-handed broadband Cholesteric Liquid Crystal film layer 115 which transmits left-handed circularly polarized white incident light and reflects right-handed circularly polarized white incident light. A black matrix is provided by black matrix layer 85 by physically blocking transmission of light into the left-handed reflective color filter layers 40 and 50. After layer 50, red (R) green (G) and blue (B) left-handed circularly polarized light is transmitted through left-

handed cholesteric liquid crystal color filter layers 40 and 50. A quarter-wave plate 80 adjacent reflective cholesteric liquid crystal color filters in layer 40 transforms the transmitted left-handed circularly polarized light into linearly polarized light, which is used in liquid crystal displays. Quarter-wave plates can be used to convert circularly polarized light to linearly polarized light for any of the embodiments shown for devices using linearly polarized light, such as displays having twisted nematic phase to activate the transmission of selected component of light through the pixels in the displays.

Fig. 41 shows a modification of the spectral filter structure of Fig. 11, wherein a source of white unpolarized light incident on a right-handed cholesteric liquid crystal layer 115 for transmitting a broad band left-handed circularly polarized light covering the primary colors and reflecting the complimentary right-handed circularly polarized light. When the green-red (G,R) portion of layer 60 overlaps the blue-green (B,G) portion and the blue (B) portion of layer 70, a black matrix is created at the overlapped portion, which separates the transmitted colors as described above. The transmitted light from layer 70 then passes through the quarter-wave plate 80 and is converted to linearly polarized light, making it suitable for use in a display which uses twisted nematic or super twisted nematic CLC elements to actively-control the transmission of selected spatial components through the pixel structures of the spectral filter in conjunction with a broad-band linear polarizing analyzer. The ability to embody a black matrix structure into the spectral filter structure improves color contrast, and eliminates the need to deposit layers for reflective masking, or other means of blocking light to form the black matrix structures employed in prior art devices.

The modifications described above are merely exemplary. It is understood that other modifications to the illustrative embodiments will readily occur to persons with ordinary skill in the art. All such modifications and variations are deemed to be within the scope and spirit of the present invention as defined by the accompanying Claims to Invention.

CLAIMS TO INVENTION:

## 1. A reflective cholesteric liquid crystal color filter comprising:

a first layer of reflective cholesteric liquid crystal color filters of one handedness having at least a first light reflecting portion reflecting a first bandwidth around a first center wavelength and a second light reflecting portion reflecting a second bandwidth around a second center wavelength and,

a second layer of reflective cholesteric liquid crystal color filters of the same handedness as the first layer having at least a third light reflecting portion reflecting a third bandwidth around a third center wavelength, and a fourth light reflecting portion reflecting a fourth bandwidth around a fourth center wavelength, the second layer of reflective cholesteric liquid crystal color filters adjacent the first layer of reflective cholesteric liquid crystal color filters such that adjacent first and second layer reflecting portions reflect different wavelengths of incident light of the same handedness and transmit the remaining wavelengths.

## 2. The reflective cholesteric liquid crystal color filter of claim 1, wherein

the first reflecting portion overlaps the third and fourth reflecting portions and the fourth reflecting portion overlaps the first and second reflecting portions,

the second reflecting portion and the third reflecting portion do not overlap each other and reflect the same wavelengths,

such that three bands of wavelengths are transmitted through the two layers.

## 3. The reflective cholesteric liquid crystal color filter of claim 2, wherein

the three center wavelengths are for the colors red-green and blue.

## 4. The reflective cholesteric liquid crystal color filter of claim 3, wherein

the bandwidths are narrow such that they are matched to the bandwidths of the incident light.

## 5. The reflective cholesteric liquid crystal color filter of claim 1, wherein

the two layers of reflective cholesteric liquid crystal color filters are replaced with one layer having a top portion of cholesteric liquid crystals polymerized to reflect a different wavelength and band width of light than the bottom portion.



6. The reflective cholesteric liquid crystal color filter of claim 2, wherein

third and forth layers of cholesteric liquid crystals are added, the third layer matching the first layer except with opposite handedness and the forth layer matching the second layer except with opposite handedness such that any incident light with a selected color is transmitted through the color filters and incident light for all other colors is reflected.

7. The reflective cholesteric liquid crystal color filter of claim 1, wherein

the first bandwidth includes the colors blue and green, and the third bandwidth includes the colors green and red,

the second bandwidth includes the color blue and the fourth bandwidth includes the color red,

a clear transparent portion in the second layer is paired vertically with the first bandwidth,

a clear transparent portion in the first layer is paired vertically with the third bandwidth,

and the fourth reflective portion in the second layer is paired vertically with the second reflective portion in the first layer,

such that red is transmitted through the first bandwidth, blue is transmitted through the third bandwidth and green is transmitted through the second and forth bandwidths to provide the primary colors for a display.

8. The reflective cholesteric liquid crystal color filter of claim 7, wherein

the third reflective portions overlap the first reflecting portions and the second reflecting portions and the first reflective portions overlap the third and forth reflective portions, such that a black matrix is formed by reflecting all light in the overlapping portions.

9. The reflective cholesteric liquid crystal color filter of claim 7, wherein

third and forth layers of cholesteric liquid crystals are added, the third layer matching the first layer except with opposite handedness and the forth layer matching the second layer except with opposite handedness such that any incident light with a selected color is transmitted through the color filters and incident light for all other colors is reflected.

10. The reflective cholesteric liquid crystal color filter of claim 8, wherein  
third and forth layers of cholesteric liquid crystals are added, the third layer matching the first layer except with opposite handedness and the forth layer matching the second layer except with opposite handedness such that any incident light with a selected color is transmitted through the color filters and incident light for all other colors is reflected.
11. The reflective cholesteric liquid crystal color filter of claim 2, wherein  
a circular polarizer of opposite handedness of the cholesteric liquid crystals in the first and second layers polarizes unpolarized light incident thereon,  
a black matrix layer blocks light from the polarizer before it is transmitted to the first and second layers,  
a quarter-wave plate converts the circularly polarized light transmitted by the first and second layers into linearly polarized light.
12. The reflective cholesteric liquid crystal color filter of claim 2, wherein  
an added layer of reflective color filters forms a black matrix by overlapping the color filters in the first and second layers to reflect the colors not reflected by the first and second layers.
13. The reflective cholesteric liquid crystal color filter of claim 12, wherein  
a circular polarizer of opposite handedness of the cholesteric liquid crystals in the first and second layers polarizes unpolarized light incident thereon,  
a quarter-wave plate converts the circularly polarized light transmitted by the first and second layers into linearly polarized.
14. The reflective cholesteric liquid crystal color filter of claim 7, wherein  
a circular polarizer of opposite handedness of the cholesteric liquid crystals in the first and second layers polarizes unpolarized light incident thereon,  
a black matrix layer blocks light from the polarizer before it is transmitted to the first and second layers,  
a quarter-wave plate converts the circularly polarized light transmitted by the first and second layers into linearly polarized light.
15. The reflective cholesteric liquid crystal color filter of claim 8, wherein

a circular polarizer of opposite handedness of the cholesteric liquid crystals in the first and second layers polarizes unpolarized light incident thereon,

a quarter-wave plate converts the circularly polarized light transmitted by the first and second layers into linearly polarized light.

16. The reflective cholesteric liquid crystal color filter of claim 11, wherein  
the circular polarizer is a broad band cholesteric liquid crystal polarizer.

17. The reflective cholesteric liquid crystal color filter of claim 14, wherein  
the circular polarizer is a broad band cholesteric liquid crystal polarizer.

18. The reflective cholesteric liquid crystal color filter of claim 15, wherein  
the circular polarizer is a broad band cholesteric liquid crystal polarizer.

19. The reflective cholesteric liquid crystal color filter of claim 1, wherein  
the first layer of reflective cholesteric liquid crystal color filters of one handedness has a fifth reflecting portion having a fifth bandwidth around a fifth center wavelength,  
the second layer of reflective cholesteric liquid crystal color filters of one handedness has a sixth reflecting portion having a sixth bandwidth around a sixth center wavelength,  
the bandwidths and center wavelengths of the first layer and the second layer are the same, and overlap each other such that the first reflecting portion is vertically adjacent the third and fourth reflective portions, the second reflective portion is vertically adjacent the fourth and sixth reflective portions and the fifth reflective portion is vertically adjacent the sixth and third reflective portions,

plus a third and a fourth layer identical to the first and second layers with opposite handedness, the third and fourth layers aligned to match the reflecting portion positions of the first and second layers, such that any incident light with a selected color is transmitted through the color filters and incident light for all other colors is reflected.

20. The reflective cholesteric liquid crystal color filter of claim 19, wherein  
the three center wavelengths are for the colors red-green and blue.

21. The reflective cholesteric liquid crystal color filter of claim 2, wherein

the layers are used in displays having an array of pixels each pixel having three subpixels, the width of each light reflecting portions in each layer extends for two subpixels of a first color and four subpixels of a second color.

22. The reflective cholesteric liquid crystal color filter of claim 21, wherein

the first layer has repeating pattern with a green light reflecting portion having a width of two subpixels and a red light reflecting portion having a width of four subpixels, and the second layer has repeating pattern with a green light reflecting portion having a width of two subpixels and a blue light reflecting portion having a width of four subpixels.

23. The reflective cholesteric liquid crystal color filter of claim 12, wherein

the layers are used in displays having an array of pixels each pixel having three subpixels, the width of each light reflecting portions in each layer extends for two subpixels of a first color and four subpixels of a second color.

24. The reflective cholesteric liquid crystal color filter of claim 1, wherein

the layers are used in displays having an array of pixels, each pixel having three subpixels, where the adjacent pixels have reversed subpixel patterns such that adjacent pixels have reflective color portions two subpixel widths in size, half in each pixel, for ease of manufacture.

25. The reflective cholesteric liquid crystal color filter of claim 2, , wherein

the layers are used in displays having an array of pixels, each pixel having three subpixels, where the adjacent pixels have reversed subpixel patterns such that adjacent pixels have reflective color portions two subpixel widths in size, half in each pixel, for ease of manufacture.

26. The reflective cholesteric liquid crystal color filter of claim 7, , wherein

the layers are used in displays having an array of pixels, each pixel having three subpixels, where the adjacent pixels have reversed subpixel patterns such that adjacent pixels have reflective color portions two subpixel widths in size, half in each pixel, for ease of manufacture.

27. The reflective cholesteric liquid crystal color filter of claim 8, wherein

the layers are used in displays having an array of pixels, each pixel having three subpixels, where the adjacent pixels have reversed subpixel patterns such that adjacent pixels have reflective color portions two subpixel widths in size, half in each pixel, for ease of manufacture.

28. The reflective cholesteric liquid crystal color filter of claim 12, wherein

the layers are used in displays having an array of pixels, each pixel having three subpixels, where the adjacent pixels have reversed subpixel patterns such that adjacent pixels have reflective color portions two subpixel widths in size, half in each pixel, for ease of manufacture.

29. The reflective cholesteric liquid crystal color filter of claim 1, wherein

a display having rows and columns of subpixels for a display array has at least two rows and at least two columns of two layers of reflecting color filters for pixels such that there are four subpixels per pixel.

30. The reflective cholesteric liquid crystal color filter of claim 29, wherein

each pixel has a red, a green, a blue and a white transmitting subpixel.

31. The reflective cholesteric liquid crystal color filter of claim 29, wherein

at least two adjacent subpixels in a layer have the same color for ease of manufacturing the displays.

32. The reflective cholesteric liquid crystal color filter of claim 29, wherein

at least one row of adjacent subpixels in a layer have the same color for ease of manufacturing the displays.

33. The reflective cholesteric liquid crystal color filter of claim 29, wherein

at least one column adjacent subpixels in a layer have the same color for ease of manufacturing the displays.

34. The reflective cholesteric liquid crystal color filter of claim 1, wherein

the light entering the reflective cholesteric liquid crystal color filter emanates from a backlight and is collimated in a collimator and then enters a reflective polarizer for

providing a wide viewing angle without color distortion in the reflective cholesteric liquid crystal color filters,

the light then enters the reflective cholesteric liquid crystal color filter where the adjacent first and second layer reflecting portions reflect different wavelengths of incident light of the same handedness and transmit the remaining wavelengths,

the transmitted light enters a quarter-wave plate to be linearly polarized,

the linearly polarized light then enters a liquid crystal light valve to selectively pass light therethrough,

light passing through the light valve passes through an analyzer and a diffuser to illuminate a color display.

35. The reflective cholesteric liquid crystal color filter of claim 2, wherein

the light entering the reflective cholesteric liquid crystal color filter emanates from a backlight and is collimated in a collimator and then enters a reflective polarizer for providing a wide viewing angle without color distortion in the reflective cholesteric liquid crystal color filters,

the light then enters the reflective cholesteric liquid crystal color filter where the adjacent first and second layer reflecting portions reflect different wavelengths of incident light of the same handedness and transmit the remaining wavelengths,

the transmitted light enters a quarter-wave plate to be linearly polarized,

the linearly polarized light then enters a liquid crystal light valve to selectively pass light therethrough,

light passing through the light valve passes through an analyzer and a diffuser to illuminate a color display.

36. The reflective cholesteric liquid crystal color filter of claim 7, wherein

the light entering the reflective cholesteric liquid crystal color filter emanates from a backlight and is collimated in a collimator and then enters a reflective polarizer for providing a wide viewing angle without color distortion in the reflective cholesteric liquid crystal color filters,

the light then enters the reflective cholesteric liquid crystal color filter where the adjacent first and second layer reflecting portions reflect different wavelengths of incident light of the same handedness and transmit the remaining wavelengths,

the transmitted light enters a quarter-wave plate to be linearly polarized,

the linearly polarized light then enters a liquid crystal light valve to selectively pass light therethrough,

light passing through the light valve passes through an analyzer and a diffuser to illuminate a color display.

37. The reflective cholesteric liquid crystal color filter of claim 29, wherein

the light entering the reflective cholesteric liquid crystal color filter emanates from a backlight and is collimated in a collimator and then enters a reflective polarizer for providing a wide viewing angle without color distortion in the reflective cholesteric liquid crystal color filters,

the light then enters the reflective cholesteric liquid crystal color filter where the adjacent first and second layer reflecting portions reflect different wavelengths of incident light of the same handedness and transmit the remaining wavelengths,

the transmitted light enters a quarter-wave plate to be linearly polarized,

the linearly polarized light then enters a liquid crystal light valve to selectively pass light therethrough,

light passing through the light valve passes through an analyzer and a diffuser to illuminate a color display.

38. A process for manufacturing a reflective cholesteric liquid crystal color filter comprising the steps of:

(a) mixing a cholesteric liquid crystal material subject to polymerization by exposure to a specific frequency ultraviolet light at a specific temperature for a specific time to yield a specific color band of reflection from a pitch gradient in the cholesteric liquid crystal when polymerized;

(b) degassing the mixture in a vacuum;

sandwiching the mixture of cholesteric liquid crystal material between a top substrate and a bottom substrate;

(c) partially masking one of the substrates to block UV light passing therethrough to prevent polymerization of the mixture of cholesteric liquid crystal material in the masked portion;

(d) setting the temperature of the mixture of cholesteric liquid crystal material to a first specific temperature;

(e) exposing the unmasked mixture of cholesteric liquid crystal material to a first UV radiation for a first length of time which will polymerize the mixture of cholesteric liquid crystal material to reflect a first color of light in a first band width;

(f) unmasking the mixture of cholesteric liquid crystal material;

(g) setting the temperature of the mixture of cholesteric liquid crystal material to a second specific temperature; and

(h) exposing the unmasked mixture of cholesteric liquid crystal material to a second UV radiation for a second length of time which will polymerize the mixture of cholesteric liquid crystal material to reflect a second color of light in a second band width to form a reflective cholesteric liquid color filter layer.

39. The process of claim 38 wherein:

the mixture of cholesteric liquid crystal material being  
a left-handed cholesteric liquid crystal polymer blue polysiloxane, SLM 90032 (Wacker), approximately 84.1% by weight  
a low molecular weight nematic liquid crystal, EMI E44 approximately 14.8% by weight,  
a left-handed chiral dopant EMI S1011, approximately 0.1% by weight,  
a photo initiator Ciba-Geigy IG184 approximately 1%

the first temperature is set to approximately 100° C and the unmasked mixture of cholesteric liquid crystal material exposed to Ultraviolet light of about 360 nm wavelength at an intensity of about 2.77 mW/cm<sup>2</sup> for about 17 seconds, to make a blue reflecting cholesteric liquid crystal portion,

lower the mixture of cholesteric liquid crystal material to 61° C for about 5 minutes to control the bandwidth of the green reflecting cholesteric liquid crystal subpixel,

the second temperature is set to approximately 61° C and all of the mixture of cholesteric liquid crystal material exposed to the second UV radiation of about 360 nm wavelength at an intensity of about 1.00 mW/cm<sup>2</sup> for about 150 seconds, to make a green reflecting cholesteric liquid crystal portion,

exposing the layer to a third temperature of about 61° C, for a third time of approximately 60 seconds at the third ultraviolet light intensity at about 20 mW/cm<sup>2</sup>.

40. The process of claim 39, wherein

the substrates are mechanically sheared while at 100° C before the mask is applied.

41. The process of claim 39, wherein



the mask applied has openings for two separate adjacent subpixels.

42. The process of claim 39, wherein

the mask applied has openings for one large pixel.

43. The process of claim 38 wherein:

the mixture of cholesteric liquid crystal material is a left-handed cholesteric liquid crystal polymer blue polysiloxane, Wacker SLM 90032, approximately 79% by weight a low molecular weight nematic liquid crystal, EMI E44 approximately 20% by weight, and a photo-initiator Ciba-Geigy IG184 approximately 1%;

the first temperature is set to approximately 58° C and the unmasked mixture of cholesteric liquid crystal material exposed to ultraviolet light of about 360 nm wavelength at an intensity of about 1.0 mW/cm<sup>2</sup> for about 77 seconds, to make a red-reflecting cholesteric liquid crystal portion;

the mixture of cholesteric liquid crystal material is raised to 83° C for about 5 minutes to control the bandwidth of the red-reflecting cholesteric liquid crystal polymer;

the second temperature set to approximately 70° C and all of the mixture of cholesteric liquid crystal material exposed to the second UV radiation of about 360 nm wavelength at an intensity of about 20.00 mW/cm<sup>2</sup> for about 60 seconds, to make a green-reflecting cholesteric liquid crystal portion.

44. The process of claim 43 wherein:

the substrates are mechanically sheared while at 58° C before the mask is applied.

45. The process of claim 43 wherein:

the mask applied has openings for two separate adjacent subpixels.

46. The process of claim 43 wherein:

the mask applied has openings for one large pixel.

47. The process of claim 38 wherein the reflective cholesteric liquid color filter layer of claim 39 and the reflective cholesteric liquid color filter layer of claim 43 are glued together to form a reflective color filter for a display.

48. The process of claim 38 wherein:

the mixture of cholesteric liquid crystal material is  
a left-handed cholesteric liquid crystal polymer blue polysiloxane, Wacker SLM 90032,  
approximately 63% by weight,  
a low molecular weight nematic liquid crystal, EMI E44 approximately 28.6% by weight,  
a low molecular weight nematic liquid crystal, SLICHEM TEB30 approximately  
8.4% by weight, and  
a photo-initiator Ciba-Geigy IG184 approximately 0.35% of polymer;  
the first temperature is set to approximately 75° C and the unmasked mixture of  
cholesteric liquid crystal material exposed to Ultraviolet light of about 360 nm wavelength  
at an intensity of about 0.1 mW/cm<sup>2</sup> for about 20 seconds, to make a red reflecting  
cholesteric liquid crystal portion,

the unmasked mixture of cholesteric liquid crystal material is then re-exposed at  
75°C with a collimated UV of about 360nm at another intensity of about 10mW/cm<sup>2</sup> for  
about 30 seconds,

a portion of the mask is removed to expose another portion of the cholesteric liquid  
crystal material,

while the cholesteric liquid crystal material is still at about 75° C, the unmasked  
portion is opposed to ultraviolet light 360 nm wavelength at an intensity of about 0.1  
mW/cm<sup>2</sup> for about 40 seconds, to polymerize the red-green reflecting portion,

the unmasked mixture of cholesteric liquid crystal material is then re-exposed at  
75°C with a collimated UV of about 360nm at another intensity of about 10mW/cm<sup>2</sup> for  
about 30 seconds, the second temperature is set to approximately 150° C and all of the  
mixture of cholesteric liquid crystal material exposed to the UV radiation of about 360 nm  
wavelength at an intensity of about 20 mW/cm<sup>2</sup> for about 150 seconds resulting in a red-  
green reflecting portion, a red reflecting portion and a clear portion of the layer.

49. The process of claim 48 wherein:

the substrates are mechanically sheared while at 75° C before the mask is applied.

50. The process of claim 38 wherein:

the mixture of cholesteric liquid crystal material is

a left-handed cholesteric liquid crystal polymer blue polysiloxane, Wacker  
SLM 90032, approximately 47.5% by weight,

a left-handed cholesteric liquid crystal polymer blue polysiloxane, Wacker  
SLM 90031, approximately 19.1% by weight,

a low molecular weight nematic liquid crystal, EMI E44 approximately 32.1% by weight,  
a chiral dopant EMI S1011, 1.3% by weight, and  
a photo initiator Ciba-Geigy IG184 approximately 0.35% of polymer;  
the first temperature is set to approximately 75° C and the unmasked mixture  
of cholesteric liquid crystal material is exposed to ultraviolet light of about 360 nm  
wavelength at an intensity of about 0.1 mW/cm<sup>2</sup> for about 20 seconds, to make a blue  
reflecting cholesteric liquid crystal portion,

the unmasked mixture of cholesteric liquid crystal material is then re-exposed  
at 75°C with a collimated UV of about 360nm at another intensity of about 10mW/cm<sup>2</sup> for  
about 30 seconds, before unmasking the substrate, a portion of the mask is removed to  
expose another portion of the cholesteric liquid crystal material, while the cholesteric liquid  
crystal material still at about 75° C the unmasked portion is exposed to ultraviolet light 360  
nm wavelength at an intensity of about 0.1 mW/cm<sup>2</sup> for about 40 seconds, to polymerize  
the blue-green reflecting portion,

the unmasked mixture of cholesteric liquid crystal material is then re-exposed  
at 75°C with a collimated UV of about 360nm at another intensity of about 10mW/cm<sup>2</sup> for  
about 30 seconds, the remainder of the mask is removed, the second temperature is set to  
approximately 150° C and all of the mixture of cholesteric liquid crystal material exposed to  
the UV radiation of about 360 nm wavelength at an intensity of about 20 mW/cm<sup>2</sup> for  
about 150 seconds, resulting in a blue-green reflecting portion, a blue reflecting portion and  
a clear portion in the layer.

51. The process of claim 50 wherein:

the substrates are mechanically sheared while at 75° C before the mask is applied.

52. The process of claim 38 wherein the reflective cholesteric liquid color filter layer of claim  
48 and the reflective cholesteric liquid color filter layer of claim 50 are glued together to  
form a reflective color filter for a display.

53. The process of claim 38, wherein

the first and second frequency ultraviolet radiation being attenuated half way  
through the reflective cholesteric color filter layer to polymerize only one half the layer,

the steps of claim 38 are repeated substituting third and fourth temperatures and  
ultraviolet radiations for the first and second temperatures and ultraviolet radiations such

that the radiation is attenuated half way through the reflective cholesteric color filter layer to polymerize the second half of the layer.

54. The process of claim 43, wherein

the layer is inverted such that the third and fourth ultraviolet radiations enter the layer from the opposite side from the first and second ultraviolet radiations.

55. The process of claim 53, wherein

the third and fourth ultraviolet radiations enter the layer from the same side as the first and second ultraviolet radiations.

56. The process of claim 53, wherein

a quarter-wave plate is polymerized as a first step, having a temperature and an ultraviolet radiation for polymerizing the quarter-wave plate.

57. The process of claim 56, wherein

there are three subpixels each having a different quarter-wave plate for a different primary color, each quarter-wave plate having a separate mask, a separate temperature of polymerization and a separate ultraviolet radiation to polymerize the cholesteric liquid crystal material in the quarter-wave plate.

58. The process of claim 56, wherein

a broadband polarizer cholesteric liquid crystal is polymerized on the opposite side of the layer from the quarter-wave plate by the layer being set to at least one polymerization temperature and irradiated with at least one ultraviolet radiation to polymerize the broadband cholesteric liquid crystal material.

59. The process of claim 57, wherein

a broadband polarizer cholesteric liquid crystal is polymerized on the opposite side of the layer from the quarter-wave plate by the layer being set to at least one polymerization temperature and irradiated with at least one ultraviolet radiation to polymerize the broadband cholesteric liquid crystal material.

60. The process of claim 59, wherein

there are three subpixels each having a different quarter-wave plate for a different primary color, each quarter-wave plate having a separate mask, a separate temperature of polymerization and a separate ultraviolet radiation to polymerize the cholesteric liquid crystal material in the quarter-wave plate.

61. The process of claim 53, wherein

the first and second ultraviolet radiation being attenuated one fourth way through the reflective cholesteric color filter layer to polymerize only one fourth of the layer,

the steps of claim 38 are repeated substituting third and fourth temperatures and ultraviolet radiations for the first and second temperatures and ultraviolet radiations such that the radiation is attenuated from one fourth way through the reflective cholesteric color filter layer to one half way through the reflective cholesteric color filter layer to polymerize the second one fourth the layer, flipping the layer over,

the steps of claim 38 are repeated substituting fifth and sixth temperatures and ultraviolet radiations for the first and second temperatures and ultraviolet radiations such that the frequency is attenuated one fourth way through the reflective cholesteric color filter layer to polymerize the only one fourth of the layer,

the steps of claim 38 are repeated substituting seventh and eight temperatures and ultraviolet radiations for the first and second temperatures and ultraviolet radiations such that the frequency is attenuated from one fourth way through the reflective cholesteric color filter layer to one half way through the reflective cholesteric color filter layer to polymerize the second one fourth the layer, such that a four portion stack of reflective cholesteric liquid crystal materials is created in one layer.

62. The process of claim 53, wherein

a reflective cholesteric liquid crystal layer forms a black matrix when combined with the two portions of the reflective cholesteric liquid crystal portions in the layer of claim 16 is polymerized as a first step, having a first mask and a first reflective matrix component temperature and ultraviolet radiation and a second mask and a second reflective matrix component temperature and ultraviolet radiation such that all incident light is reflected from the three portion stack of cholesteric liquid crystal material in the layer to form a black matrix.

63. The process of claim 38, wherein

there is a third unmasking step for unmasking a third portion of the mixture of cholesteric liquid crystal material,

setting the temperature of the mixture of cholesteric liquid crystal material to a third specific temperature,

the unmasked mixture of cholesteric liquid crystal material to a third ultraviolet radiation for a third length of time which will polymerize the mixture of cholesteric liquid crystal material to a clear isotropic polymer to transmit all light,

the first and second and third ultraviolet radiation being attenuated half way through the reflective cholesteric color filter layer to polymerize only one half the layer,

the above steps are repeated substituting forth, fifth and sixth temperatures and ultraviolet radiations for the first, second and third temperatures and ultraviolet radiations such that the ultraviolet radiation is attenuated half way through the reflective cholesteric color filter layer to polymerize the second one half of the layer.

64. The process of claim 38, wherein

the masks on the first half the layer and the second half of the layer are different such that overlapping portions are polymerized to form a black matrix by reflecting all light from the overlapping portions.

65. The process of claim 64, wherein

a quarter-wave plate is polymerized as a first step, having a temperature and an ultraviolet radiation for polymerizing the quarter-wave plate.

66. The process of claim 65, wherein

there are three subpixels each having a different quarter-wave plate for a different primary color, each quarter-wave plate having a separate mask, a separate temperature of polymerization and a separate ultraviolet radiation to polymerize the cholesteric liquid crystal material.

67. The process of claim 65, wherein

a broadband polarizer cholesteric liquid crystal is polymerized on the opposite side of the layer from the quarter-wave plate by the layer being set to at least one polymerization temperature and irradiated with at least one ultraviolet radiation to polymerize the broadband cholesteric liquid crystal material.

68. The process of claim 66, wherein

a broadband polarizer cholesteric liquid crystal is polymerized on the opposite side of the layer from the quarter-wave plate by the layer being set to at least one polymerization temperature and irradiated with at least one ultraviolet radiation to polymerize the broadband cholesteric liquid crystal material.

69. The process of claim 38 wherein:

the mixture of cholesteric liquid crystal material having at least one polymerizable liquid crystal component and at least one non-polymerizable liquid crystal component.

70. The process of claim 69 wherein:

the polymerizable liquid crystal component in the mixture of cholesteric liquid crystal material is a monomer.

71. The process of claim 69 wherein:

the polymerizable liquid crystal component in the mixture of cholesteric liquid crystal material is an oligmer.

72. The process of claim 69 wherein:

the non-polymerizable liquid crystal component in the mixture of cholesteric liquid crystal material is a nematic.

73. The process of claim 69 wherein:

the non-polymerizable liquid crystal component in the mixture of cholesteric liquid crystal material is a chiral additive.

74. The process of claim 69 wherein:

the non-polymerizable liquid crystal component is phase segregated from the polymerizable liquid crystal and diffuses along the UV field to generate a pitch gradient.

75. The process of claim 73 wherein:

the diffusion rate of the non-polymerizable liquid crystal component is slower than the polymerization rate of the polymerizable liquid crystal.

76. The process of claim 73 wherein:

the pitch distribution of the cholesteric liquid crystal is nonlinear.

77. The image display panel employing the recycling of light from a plurality of light reflective elements therewithin so as to produce color images with enhanced brightness for viewing by a viewer, said image display panel comprising:

a backlighting structure including

a light source for producing light consisting of spectral components having wavelengths over a substantial portion of the visible band of said electromagnetic spectrum, and

a broad-band reflector for reflecting, within said backlighting structure, polarized light consisting of spectral components having wavelengths over a substantial portion of said visible band and, upon one or more reflections within said backlighting structure, converting the polarization state of said spectral components from a first polarization state (P1) to a second polarization state (P2) orthogonal to said first polarization state (P1), and from said second polarization state (P2) to said first polarization state (P1);

a plurality of pixel regions spatially encompassed within a predefined image display area definable relative to said backlighting structure, wherein each said pixel region spatially encompasses a plurality of subpixel regions and each said subpixel region within each said spatially-encompassing pixel region has a predefined spectral band over the visible band of the electromagnetic spectrum,

each said subpixel region within each said pixel region having a light transmission portion and a light blocking portion, and each said light transmission portion and said light blocking portion having a frontside disposed in the direction of said viewer and a backside in the direction of said backlighting structure;

a broad-band reflective polarizer for reflecting light consisting substantially of spectral components having wavelengths over a substantial portion of said visible band and said first polarization state (P1), and transmitting a distribution of polarized light along a prespecified direction, substantially confined within said predefined image display area, and consisting substantially of spectral components having wavelengths over a substantial portion of said visible band and said second polarization state (P2);

a spatial intensity modulation structure including

an array of polarization modifying elements, each said polarization modifying element being spatially registered with one said subpixel region and selectively



modifying the polarization state of polarized light transmitted therethrough in response to a subpixel drive signal provided to said polarization modifying element, and

a broad-band polarizer, cooperating with said array of polarization modifying elements, so as to modulate the spatial intensity of said produced distribution of polarized light and thereby produce a dark-type or bright-type intensity level at each said subpixel region along said broad-band polarizer; and

a spectral filtering structure having a pixelated array of pass-band reflective-type spectral filtering elements for spectrally filtering said polarized light, each said pass-band reflective-type spectral filtering element being spatially registered with one said subpixel region and tuned to one said predefined spectral band for transmitting only the spectral components of said polarized light having wavelengths within said predefined spectral band of said subpixel region, and reflecting the spectral components of said produced polarized light having wavelengths outside said predefined spectral band of said subpixel region so as to produce a predefined color value at said subpixel region spatially-registered with said pass-band reflective-type spectral filtering element;

a pattern of broad-band reflector material, in spatial registration with the backside of said light blocking portions of said subpixel regions, for reflecting produced light at the light blocking portions of said subpixel regions;

a pattern of broad-band absorption material, in spatial registration with the frontside of said light blocking portions of said subpixel regions, for absorbing ambient light incident upon said light blocking portions of said subpixel regions;

wherein, the spectral components of polarized light that are transmitted through said broad-band reflective polarizer along said prespecified direction contribute to said distribution of polarized light;

wherein, the spectral components of polarized light that are not transmitted through said broad-band reflective polarizer along said prespecified direction are reflected off said broad-band reflective polarizer and transmitted back towards said broad-band reflector for reflection and/or polarization conversion within said backlighting structure and retransmission through said broad-band reflective polarizer so as to contribute to said distribution of polarized light;

wherein, the spectral components of said polarized light that are transmitted through the pass-band reflective-type spectral filtering element at each said subpixel region within each said spatially-encompassing pixel region produce said predefined color value at said subpixel region; and

wherein, the spectral components of said polarized light that are not transmitted through the pass-band reflective-type spectral filtering element at each said subpixel region within each said spatially-encompassing pixel region are reflected off said pass-band reflective-type spectral filtering element and transmitted back towards said backlighting structure for reflection and/or polarization conversion and retransmission towards the other said subpixel regions within said spatially-encompassing pixel region in said spectral filtering structure;

wherein, the spectral components of said produced polarized that fall incident on the light blocking portions of said subpixel regions are reflected off said pattern of broad-band reflector material disposed thereon, and transmitted back towards said backlighting structure for reflection and/or polarization conversion and retransmission towards the other said subpixel regions within said spatially-encompassing pixel region in said spectral filtering structure;

wherein, the spectral components of ambient light falling incident upon the light blocking portions of said subpixel regions are absorbed by said pattern of broad-band absorption material disposed thereon, thereby reducing glare from said image display panel due to ambient light incident thereon;

whereby said color images are produced from said predefined image display area having enhanced brightness.

78. The image display panel of claim 77, wherein said pass-band reflective-type spectral filtering structure is disposed between said backlighting structure and said spatial intensity modulation structure.

79. The image display panel of claim 78, wherein said plurality of subpixel regions within each said spatially-encompassing pixel region comprise a "red" subpixel region having a "red" pass-band, a "green" subpixel region having a "green" pass-band, and a "blue" subpixel region having a "blue" pass-band.

80. The image display panel of claim 78, wherein each said pass-band reflective-type spectral filtering element is an optical element made from a material selected from the group consisting of liquid crystal material, holographic-type material, and interference-type material.

81. The image display panel of claim 78, wherein each said polarization modifying element is an optical element made from liquid crystal material.

82. The image display panel of claim 78, wherein said backlighting structure further comprises

a light guiding panel disposed between said broad-band reflector and said broad-band reflective polarizer for guiding said produced light over said predefined image display area.

83. The image display panel of claim 78, wherein said first polarization state is a first linear polarization state and said second polarization state is a second linear polarization state orthogonal to said first linear polarization state.

84. The image display panel of claim 78, wherein said first polarization state is a first circular polarization state and said second polarization state is a second circular polarization state orthogonal to said first circular polarization state.

85. The image display panel of claim 78, said broad-band reflector is a quasi-diffusive reflector.

86. The image display panel of claim 77, wherein said spatial intensity modulation structure is disposed between said backlighting structure and said spectral filtering structure- subpixel regions within each said spatially-encompassing pixel region comprise a "red" subpixel region having a "red" pass-band, a "green" subpixel region having a "green" pass-band, and a "blue" subpixel region having a "blue" pass-band.

87. The image display panel of claim 86, wherein said plurality of subpixel regions within each said spatially-encompassing pixel region comprise a "red" subpixel region having a "red" pass-band, a "green" subpixel region having a "green" pass-band, and a "blue" subpixel region having a "blue" pass-band.

88. The image display panel of claim 87, wherein said "red" pass-band transmits spectral components of light within said "red" pass-band and reflects substantially all spectral components of light within said "green" pass-band and said "blue" pass-band, wherein said "green" pass-band transmits spectral components of light within said "green" pass-band and

reflects substantially all spectral components of light within said "red" pass-band and said "blue" pass-band, and wherein said "blue" pass-band transmits spectral components of light within said "blue" pass-band and reflects substantially all spectral components of light within said "red" pass-band and said "green" pass-band.

89. The image display panel of claim 86, wherein each said spectral filtering element is an optical element made from a material selected from the group consisting of liquid crystal material, holographic-type material, and interference-type material.

90. The image display panel of claim 86, wherein each said polarization modifying element is an optical element made from liquid crystal material.

91. The image display panel of claim 87, wherein said backlighting structure further comprises

a light guiding panel disposed between said broad-band reflector and said broad-band reflective polarizing filter for guiding said produced light over said predefined image display area.

92. The image display panel of claim 86, wherein said first polarization state is a first linear polarization state and said second polarization state is a second linear polarization state orthogonal to said first linear polarization state.

93. The image display panel of claim 86, wherein said first polarization state is a first circular polarization state and said second polarization state is a second circular polarization state orthogonal to said first circular polarization state.

94. The image display panel of claim 86, said broad-band polarizing reflector is a quasi-diffusive reflector.

95. The image display panel of claim 77, wherein the spectral components of said polarized light producing said bright-type intensity level at each subpixel region within said spatially-encompassing pixel region in said spatial intensity modulation structure are transmitted through said broad-band polarizer, and

wherein, the spectral components of said polarized light not producing said bright-type intensity level are reflected off said broad-band polarizer and transmitted back towards

said backlighting structure for reflection and/or polarization conversion and retransmission towards the other said subpixel regions within said spatially-encompassing pixel region.

96. The liquid crystal display (LCD) panel construction for producing color images for viewing by a viewer, said LCD panel construction comprising:

- a plurality of pixel regions within a predefined image display area, wherein each said pixel region has a plurality of subpixel regions and each said subpixel region within each said pixel region has a light transmission portion and a light blocking portion, and each said light transmission portion and said light blocking portion having a frontside disposed in the direction of said viewer and a backside in the direction of said illumination means;

- illumination means for illuminating said plurality of pixel regions from the backside thereof so that a color image is formed from said plurality of pixel regions for viewing;

- a pattern of broad-band reflector material, in spatial registration with the backside of said light blocking portions of said subpixel regions, for reflecting produced light at structures associated with said light blocking portions of the subpixels and thereby recycling produced light for use in illuminating said plurality of pixel regions; and

- a pattern of broad-band absorption material, in spatial registration with the frontside of said light blocking portions of said subpixel regions, for absorbing ambient light incident upon structures associated with said light blocking portions of said subpixels and thereby reducing glare at the surface of the LCD panel due to ambient light incident thereon.

97. The image display panel employing the recycling of light from a plurality of light reflective elements therewithin so as to produce color images with enhanced brightness for viewing by a viewer, said image display panel comprising:

- a backlighting structure including

- a light source for producing light consisting of spectral components having wavelengths over a substantial portion of the visible band of said electromagnetic spectrum, and

- a broad-band reflector for reflecting, within said backlighting structure, polarized light consisting of spectral components having wavelengths over a substantial portion of said visible band and, upon one or more reflections within said backlighting structure, converting the polarization state of said spectral components from a first polarization state (P1) to a second polarization state (P2) orthogonal to said first polarization state (P1), and from said second polarization state (P2) to said first polarization state (P1);

a plurality of pixel regions spatially encompassed within a predefined image display area definable relative to said backlighting structure, wherein each said pixel region spatially encompasses a plurality of subpixel regions and each said subpixel region within each said spatially-encompassing pixel region has a predefined spectral band over the visible band of the electromagnetic spectrum,

each said subpixel region within each said pixel region having a light transmission portion and a light blocking portion, and each said light transmission portion and said light blocking portion having a frontside disposed in the direction of said viewer and a backside in the direction of said backlighting structure;

a broad-band reflective polarizer for reflecting light consisting substantially of spectral components having wavelengths over a substantial portion of said visible band and said first polarization state (P1), and transmitting a distribution of polarized light along a prespecified direction, substantially confined within said predefined image display area, and consisting substantially of spectral components having wavelengths over a substantial portion of said visible band and said second polarization state (P2);

a spatial intensity modulation structure including

an array of polarization modifying elements, each said polarization modifying element being spatially registered with one said subpixel region and selectively modifying the polarization state of polarized light transmitted therethrough in response to a subpixel drive signal provided to said polarization modifying element, and

a broad-band polarizer, cooperating with said array of polarization modifying elements, so as to modulate the spatial intensity of said produced distribution of polarized light and thereby produce a dark-type or bright-type intensity level at each said subpixel region along said broad-band polarizer; and

a spectral filtering structure having a pixelated array of pass-band reflective-type spectral filtering elements for spectrally filtering said polarized light, each said pass-band reflective-type spectral filtering element being spatially registered with one said subpixel region and tuned to one said predefined spectral band for transmitting only the spectral components of said polarized light having wavelengths within said predefined spectral band of said subpixel region, and reflecting the spectral components of said produced polarized light having wavelengths outside said predefined spectral band of said subpixel region so as to produce a predefined color value at said subpixel region spatially-registered with said pass-band reflective-type spectral filtering element;

a pattern of broad-band reflector material, in spatial registration with the backside of said light blocking portions of said subpixel regions, for reflecting produced light at the light blocking portions of said subpixel regions;

a pattern of broad-band absorption material, in spatial registration with the frontside of said light blocking portions of said subpixel regions, for absorbing ambient light incident upon said light blocking portions of said subpixel regions;

wherein, the spectral components of polarized light that are transmitted through said broad-band reflective polarizer along said prespecified direction contribute to said distribution of polarized light;

wherein, the spectral components of polarized light that are not transmitted through said broad-band reflective polarizer along said prespecified direction are reflected off said broad-band reflective polarizer and transmitted back towards said broad-band reflector for reflection and/or polarization conversion within said backlighting structure and retransmission through said broad-band reflective polarizer so as to contribute to said distribution of polarized light;

wherein, the spectral components of said polarized light that are transmitted through the pass-band reflective-type spectral filtering element at each said subpixel region within each said spatially-encompassing pixel region produce said predefined color value at said subpixel region; and

wherein, the spectral components of said polarized light that are not transmitted through the pass-band reflective-type spectral filtering element at each said subpixel region within each said spatially-encompassing pixel region are reflected off said pass-band reflective-type spectral filtering element and transmitted back towards said backlighting structure for reflection and/or polarization conversion and retransmission towards the other said subpixel regions within said spatially-encompassing pixel region in said spectral filtering structure;

wherein, the spectral components of said produced polarized that fall incident on the light blocking portions of said subpixel regions are reflected off said pattern of broad-band reflector material disposed thereon, and transmitted back towards said backlighting structure for reflection and/or polarization conversion and retransmission towards the other said subpixel regions within said spatially-encompassing pixel region in said spectral filtering structure;

wherein, the spectral components of ambient light falling incident upon the light blocking portions of said subpixel regions are absorbed by said pattern of broad-band absorption

material disposed thereon, thereby reducing glare from said image display panel due to ambient light incident thereon;

whereby said color images are produced from said predefined image display area having enhanced brightness.

98. The image display panel of claim 97, wherein said pass-band reflective-type spectral filtering structure is disposed between said backlighting structure and said spatial intensity modulation structure.

99. The image display panel of claim 98, wherein said plurality of subpixel regions within each said spatially-encompassing pixel region comprise a "red" subpixel region having a "red" pass-band, a "green" subpixel region having a "green" pass-band, and a "blue" subpixel region having a "blue" pass-band.

100. The image display panel of claim 98, wherein each said pass-band reflective-type spectral filtering element is an optical element made from a material selected from the group consisting of liquid crystal material, holographic-type material, and interference-type material.

101. The image display panel of claim 98, wherein each said polarization modifying element is an optical element made from liquid crystal material.

102. The image display panel of claim 98, wherein said backlighting structure further comprises

a light guiding panel disposed between said broad-band reflector and said broad-band reflective polarizer for guiding said produced light over said predefined image display area.

103. The image display panel of claim 98, wherein said first polarization state is a first linear polarization state and said second polarization state is a second linear polarization state orthogonal to said first linear polarization state.

104. The image display panel of claim 98, wherein said first polarization state is a first circular polarization state and said second polarization state is a second circular polarization state orthogonal to said first circular polarization state.



105. The image display panel of claim 98, said broad-band reflector is a quasi-diffusive reflector.
106. The image display panel of claim 97, wherein said spatial intensity modulation structure is disposed between said backlighting structure and said spectral filtering structure- subpixel regions within each said spatially-encompassing pixel region comprise a "red" subpixel region having a "red" pass-band, a "green" subpixel region having a "green" pass-band, and a "blue" subpixel region having a "blue" pass-band.
107. The image display panel of claim 106, wherein said plurality of subpixel regions within each said spatially-encompassing pixel region comprise a "red" subpixel region having a "red" pass-band, a "green" subpixel region having a "green" pass-band, and a "blue" subpixel region having a "blue" pass-band.
108. The image display panel of claim 107, wherein said "red" pass-band transmits spectral components of light within said "red" pass-band and reflects substantially all spectral components of light within said "green" pass-band and said "blue" pass-band, wherein said "green" pass-band transmits spectral components of light within said "green" pass-band and reflects substantially all spectral components of light within said "red" pass-band and said "blue" pass-band, and wherein said "blue" pass-band transmits spectral components of light within said "blue" pass-band and reflects substantially all spectral components of light within said "red" pass-band and said "green" pass-band.
109. The image display panel of claim 106, wherein each said spectral filtering element is an optical element made from a material selected from the group consisting of liquid crystal material, holographic-type material, and interference-type material.
110. The image display panel of claim 106, wherein each said polarization modifying element is an optical element made from liquid crystal material.
111. The image display panel of claim 107, wherein said backlighting structure further comprises

a light guiding panel disposed between said broad-band reflector and said broad-band reflective polarizing filter for guiding said produced light over said predefined image display area.

112. The image display panel of claim 106, wherein said first polarization state is a first linear polarization state and said second polarization state is a second linear polarization state orthogonal to said first linear polarization state.

113. The image display panel of claim 106, wherein said first polarization state is a first circular polarization state and said second polarization state is a second circular polarization state orthogonal to said first circular polarization state.

114. The image display panel of claim 106, said broad-band polarizing reflector is a quasi-diffusive reflector.

115. The image display panel of claim 87, wherein the spectral components of said polarized light producing said bright-type intensity level at each subpixel region within said spatially-encompassing pixel region in said spatial intensity modulation structure are transmitted through said broad-band polarizer, and

wherein, the spectral components of said polarized light not producing said bright-type intensity level are reflected off said broad-band polarizer and transmitted back towards said backlighting structure for reflection and/or polarization conversion and retransmission towards the other said subpixel regions within said spatially-encompassing pixel region.

116. The wide incident angle reflective broadband polarizer comprising:

a first varying pitch helix cholesteric liquid crystal film for reflecting and transmitting circularly polarized light over a broad band of wavelengths,

a first constant pitch helix cholesteric liquid crystal film for rotating the elliptical axis of light from the first varying pitch helix cholesteric liquid crystal film, adjacent the first varying pitch helix cholesteric liquid crystal film,

a first homeotropic film for compensating the phase of the light from the first constant pitch helix cholesteric liquid crystal film, adjacent the first constant pitch helix cholesteric liquid crystal film such that unpolarized light entering the first varying pitch

helix cholesteric liquid crystal film exits the first homeotropic film as circularly polarized light of one handedness for small and large angles of incidence.

117. The wide incident angle reflective broadband polarizer of claim 116 wherein:

- the helical axis of the first variable pitch helix cholesteric liquid crystal film is oriented perpendicular to the film surface,

- the helical axis of the first constant pitch helix cholesteric liquid crystal film is oriented perpendicular to the film surface,

- the long molecular axes of the first homeotropic film are aligned perpendicular to the film surface.

118. The wide incident angle reflective broadband polarizer of claim 116 wherein:

- a second varying pitch helix cholesteric liquid crystal film for reflecting and transmitting circularly polarized light over a broad band of wavelengths, adjacent the first varying pitch helix cholesteric liquid crystal film,

- a second constant pitch helix cholesteric liquid crystal film for rotating the elliptical axis of light from the second varying pitch helix cholesteric liquid crystal film, adjacent the second varying pitch helix cholesteric liquid crystal film,

- a second homeotropic film for compensating the phase of the light from the second constant pitch helix cholesteric liquid crystal film, adjacent the second constant pitch helix cholesteric liquid crystal film, such that unpolarized light incident on either homeotropic film of the wide incident angle broadband polarizer is transmitted as circularly polarized light of one handedness for small and large angles of incidence and reflected as circularly polarized light of the opposite handedness for small and large angles of incidence.

119. The wide incident angle reflective broadband polarizer of claim 116 wherein:

- a second constant pitch helix cholesteric liquid crystal film for rotating the elliptical axis of light from the first varying pitch helix cholesteric liquid crystal film, adjacent the first varying pitch helix cholesteric liquid crystal film,

- a second homeotropic film for compensating the phase of the light from the second constant pitch helix cholesteric liquid crystal film, adjacent the second constant pitch helix cholesteric liquid crystal film such that unpolarized light incident on either homeotropic film of the wide incident angle broadband polarizer is transmitted as circularly polarized light of one handedness for small and large angles of incidence and reflected as circularly polarized light of the opposite handedness for small and large angles of incidence.

120. The wide incident angle reflective broadband polarizer of claim 118 wherein:

the wide angle broadband polarizer of claim 118 is encased in a block of transparent material diagonally to form a prism such that unpolarized light incident on one prism face will be transmitted as circularly polarized light of one handedness and reflected as circularly polarized light of the opposite handedness perpendicular to the transmitted light.

121. The wide incident angle reflective broadband polarizer of claim 120 wherein:

a prism of claim 120 having varying pitch helix cholesteric liquid crystal film for reflecting and transmitting circularly polarized light over a broadband of wavelengths of one handedness is adjacent to,

a prism of claim 120 having a varying pitch helix cholesteric liquid crystal film for reflecting and transmitting circularly polarized light over a broadband of wavelengths of the opposite handedness,

a mirror adjacent one of the prisms for changing the handedness of the reflected light and reflecting the reflected light to the prism with the opposite handedness for reflection in the same direction as the incident light such that incident unpolarized light converts totally to transmitted circularly polarized light of one handedness.

122. The wide incident angle reflective broadband polarizer of claim 118, wherein

a mirror placed parallel to the wide incident angle broadband polarizer,

a light source for producing unpolarized light is placed between the mirror and the wide incident angle broadband polarizer, such that light from the light source is polarized when it is transmitted through the wide incident angle broadband polarizer as circularly polarized light of one handedness.

123. The wide incident angle reflective broadband polarizer of claim 122, wherein

a quarter-wave plate placed adjacent the wide incident angle broadband polarizer on the side opposite the mirror such that linearly polarized light from the quarter-wave plate is chromatically stable at any viewing azimuthal and polar angle.

124. The wide incident angle reflective broadband polarizer of claim 119 wherein:

the wide angle broadband polarizer of claim 119 is encased in a block of transparent material diagonally to form a prism such that unpolarized light incident on one prism face

will be transmitted as circularly polarized light of one handedness and reflected as circularly polarized light of opposite handedness perpendicular to the transmitted light.

125. The wide incident angle reflective broadband polarizer of claim 124 wherein:

a prism of claim 124 having varying pitch helix cholesteric liquid crystal film for reflecting and transmitting circularly polarized light over a broadband of wavelengths of one handedness is adjacent to,

a prism of claim 9 having a varying pitch helix cholesteric liquid crystal film for reflecting and transmitting circularly polarized light over a broadband of wavelengths of the opposite handedness,

a mirror adjacent one of the prisms for changing the handedness of the reflected light and reflecting the reflected light to the prism with the opposite handedness for reflection in the same direction as the incident light such that incident unpolarized light converts totally to transmitted circularly polarized light of one handedness.

126. The wide incident angle reflective broadband polarizer of claim 124, wherein

a mirror placed parallel to the wide incident angle broadband polarizer,

a light source for producing unpolarized light is placed between the mirror and the wide incident angle broadband polarizer, such that light from the light source is polarized when it is transmitted through the wide incident angle broadband polarizer as circularly polarized light of one handedness.

127. The wide incident angle reflective broadband polarizer of claim 126, wherein

a quarter-wave plate placed adjacent the wide incident angle broadband polarizer on the side opposite the mirror such that linearly polarized light from the quarter-wave plate is chromatically stable at any viewing azimuthal and polar angle.

128. The wide incident angle reflective broadband polarizer of claim 116, wherein the homeotropic film is polymerizable.

129. The wide incident angle reflective broadband polarizer of claim 116, wherein the constant pitch helix cholesteric liquid crystal film is polymerizable.

130. The wide incident angle reflective broadband polarizer of claim 116, wherein incident unpolarized visible light is transmitted as circularly polarized light.

131. The wide incident angle reflective broadband polarizer of claim 116, wherein incident unpolarized ultraviolet light is transmitted as circularly polarized light.
132. The wide incident angle reflective broadband polarizer of claim 116, wherein incident unpolarized infrared light is transmitted as circularly polarized light.
133. The wide incident angle reflective broadband polarizer of claim 116, wherein an electric field is applied to the varying pitch helix cholesteric liquid crystal film to switch the film between a totally transmissive state and a circularly polarizing transmitting state.
134. The wide incident angle reflective broadband polarizer of claim 116, wherein a first index matching adhesive binds the first varying pitch helix cholesteric liquid crystal film to the first constant pitch helix cholesteric liquid crystal film and a second index matching adhesive binds first constant pitch helix cholesteric liquid crystal film to the first homeotropic film.
135. The wide incident angle reflective broadband polarizer of claim 116, wherein the film of claim 116 is broken up into fragments and used as a pigment.
136. The wide incident angle reflective broadband polarizer of claim 118, wherein the film of claim 119 is broken up into fragments and used as a pigment.
137. The wide incident angle reflective broadband polarizer of claim 119, wherein the film of claim 119 is broken up into fragments and used as a pigment.
138. A wide incident angle reflective broadband polarizer of claim 116, wherein the wide incident angle broadband polarizer installed in a reflective cholesteric liquid crystal color filter display corrects for color distortions over large viewing angles.
139. A wide incident angle reflective broadband polarizer of claim 118, wherein the wide incident angle broadband polarizer installed in a reflective cholesteric liquid crystal color filter display corrects for color distortions over large viewing angles.

140. A wide incident angle reflective broadband polarizer of claim 120, wherein  
the wide incident angle broadband polarizer installed in a reflective cholesteric liquid crystal color filter display corrects for color distortions over large viewing angles.
141. The wide incident angle reflective broadband polarizer of claim 116, wherein  
the wide incident angle broadband polarizer installed in a smart window corrects for color distortions over large viewing angles.
142. The wide incident angle reflective broadband polarizer of claim 118, wherein  
the wide incident angle reflective broadband polarizer installed in a smart window corrects for color distortions over large viewing angles.
143. The wide incident angle reflective broadband polarizer of claim 119, wherein  
the wide incident angle broadband polarizer installed in a smart window corrects for color distortions over large viewing angles.
144. The wide incident angle reflective broadband polarizer of claim 116, wherein  
a wide incident angle broadband polarizer of claim 116 with opposite handedness is attached to reflect all incident light.
145. The wide incident angle reflective broadband polarizer of claim 116 wherein an electrically addressable  $\pi$  phase shifter is sandwiched between the wide incident angle broadband polarizer of claim 116 with one handedness and the wide incident angle broadband polarizer of claim 116 with either handedness such that all incident light is reflected when the  $\pi$  phase shifter changes the light incident thereon and transmits light when the  $\pi$  phase shifter is quiescent.
146. The liquid crystal display (LCD) panel construction comprising:  
backlighting structure including a light guiding panel, a pair of edge-illuminating light sources, and a quasi-specular reflector;  
broad-band polarizing reflective panel;  
an array of spectral filtering elements realized as an array of pass-band polarizing reflective elements;  
a spatial-intensity modulating array realized as an array of electronically-controlled polarization rotating elements.

- a broad-band polarizing reflective pixel analyzing panel;
- a polarization-state preserving light diffusive film layer disposed thereon for ensuring uniform spatial light intensity across the LCD panel and thus improve the viewing angle of the system; and
- a quasi-collimating (i.e. condensing) film layer disposed between said polarization-state preserving light diffusive film layer and said broad-band polarizing reflective panel.

147. A liquid crystal display (LCD) panel assembly comprising:

- a two-layer CLC-based spectral filtering structure; and
- a liquid crystal (LC) spatial-intensity modulation panel, said two-layer CLC-based spectral filtering structure including first and second CLC layers, and
- a plurality of pixel structures formed in said first and second CLC layers,

wherein each said pixel structure has red, blue and green subpixel structures, and

wherein each blue subpixel structure therein is realized by a green-band reflecting region in the first CLC layer and a red band reflecting region in the second CLC layer,

wherein each green subpixel structure therein is realized by a blue band reflecting region in the first CLC layer and a red band reflecting region in the second CLC layer,

wherein each red subpixel structure therein is realized by a blue band reflecting region in the first CLC layer and a green-band reflecting region in the second CLC layer, and

wherein a patterned broad-band CLC reflective layer is provided beneath the first CLC layer in order to realize a broad-band inter-subpixel "white" reflective matrix-like pattern between neighboring subpixel regions in order to improve light recycling off thin-film transistors (TFTs) and associated wiring regions surrounding the light transmission aperture of each and every subpixel.

148. The LCD panel assembly having improved angular viewing performance, comprising:

- a light diffusing layer operably associated with a backlighting panel;
- a broad-band CLC-based reflective polarizer operably connected to said backlighting panel;
- a CLC-based spectral filtering structure;
- a spatial intensity modulation structure including a broad band analyzer; and
- a light condensing (i.e. quasi-collimating) film disposed between said light diffusing layer and said broad-band CLC-based reflective polarizer; and
- a light diffusing layer mounted upon said broad-band analyzer.



149. The liquid crystal display (LCD) panel assembly comprising:
- a two-layer CLC-based spectral filtering structure; and
  - a liquid crystal (LC) spatial-intensity modulation panel, said two-layer CLC-based spectral filtering structure including first and second CLC layers, and
    - a plurality of pixel structures formed in said first and second CLC layers,
    - wherein each said pixel structure has red, blue and green subpixel structures;
    - wherein each red subpixel structure therein is realized by a green-band reflecting region in the first CLC layer and a blue band reflecting region in the second CLC layer,
    - wherein each green subpixel structure therein is realized by a band reflecting region in the first CLC layer and a clear band region in the second CLC layer,
    - wherein each blue subpixel structure therein is realized by a red band reflecting region in the first CLC layer and a green-band reflecting region in the second CLC layer, and
    - wherein a green-blue band reflecting pattern and quarter-wave retardation surface thereover are provided beneath the first CLC layer in order to realize a broad-band inter-subpixel "white" reflective matrix-like pattern between neighboring subpixel regions.
150. The liquid crystal display (LCD) panel assembly comprising:
- a two-layer CLC-based spectral filtering structure; and
  - a liquid crystal (LC) spatial-intensity modulation panel, said two-layer CLC-based spectral filtering structure including first and second CLC layers, and
    - a plurality of pixel structures formed in said first and second CLC layers,
    - wherein each said pixel structure has red, blue and green subpixel structures;
    - wherein each red subpixel structure therein is realized by a clear (non-reflecting) region in the first CLC layer and a blue-green band reflecting region in the second CLC layer,
    - wherein each blue subpixel structure therein is realized by a green-red band reflecting region in the first CLC layer and a clear (non-reflecting) region in the second CLC layer,
    - wherein each green subpixel structure therein is realized by a red band reflecting region in the first CLC layer and a blue-band reflecting region in the second CLC layer, and
    - a broad-band reflecting pattern and quarter-wave retardation surface thereover are provided beneath the first CLC layer in order to realize the broad-band inter-subpixel "white" reflective matrix-like pattern between neighboring subpixel regions.
151. The liquid crystal display (LCD) panel assembly comprising:
- a two-layer CLC-based spectral filtering structure; and

a liquid crystal (LC) spatial-intensity modulation panel, said two-layer CLC-based spectral filtering structure including first and second CLC layers, and

a plurality of pixel structures formed in said first and second CLC layers,

wherein each said pixel structure has red, blue and green subpixel structures;

wherein each red subpixel structure therein is realized by a clear (non-reflecting) region in the first CLC layer and a blue-green band reflecting region in the second CLC layer,

wherein each blue subpixel structure therein is realized by a green-red band reflecting region in the first CLC layer and a clear (non-reflecting) region in the second CLC layer,

wherein each green subpixel structure therein is realized by a red band reflecting region in the first CLC layer and a blue-band reflecting region in the second CLC layer, and

a broad-band inter-subpixel "white" type matrix-like pattern is integrally-embodied within the spectral filtering structure, between neighboring subpixel regions, by virtue of (i) the spatially-overlapping green-red band reflecting regions in the first CLC layer and the blue-green band reflecting regions in the second CLC layer, and also (ii) the spatially-overlapping green-red band reflecting regions in the first CLC layer and the blue band reflecting regions in the second CLC layer.

152. The method of fabricating a two-layer CLC-based spectral filtering structure comprising:

(a) integrally-embodiment a broad-band inter-subpixel "white" matrix-like pattern only among the subpixels of each pixel structure, but not between all neighboring pixel structures within the CLC-based spectral filtering structure.

153. The liquid crystal display (LCD) panel assembly comprising:

a two-layer CLC-based spectral filtering structure; and

a liquid crystal (LC) spatial-intensity modulation panel, said two-layer CLC-based spectral filtering structure including first and second CLC layers, and

a plurality of pixel structures formed in said first and second CLC layers,

wherein each said pixel structure has red, blue and green subpixel structures;

wherein each blue subpixel structure therein is realized by a green-band RHCP reflecting region in the first CLC layer, a red-band RHCP reflecting region in the second CLC layer, a green-band LHCP reflecting region in the third CLC layer, and a red-band LHCP reflecting region in the fourth CLC layer,

wherein each green subpixel structure therein is realized by a blue-band RHCP reflecting region in the first CLC layer, a red-band RHCP reflecting region in the second CLC layer, a blue-band LHCP reflecting region in the third CLC layer and a red-band LHCP reflecting region in the fourth CLC layer, and

wherein each red subpixel structure therein is realized by a blue-band RHCP reflecting region in the first CLC layer, a green-band RHCP reflecting region in the second CLC layer, a blue-band LHCP reflecting region in the third CLC layer, and a green-band LHCP reflecting region in the fourth CLC layer.

154. The liquid crystal display (LCD) panel assembly comprising:

a two-layer CLC-based spectral filtering structure; and

a liquid crystal (LC) spatial-intensity modulation panel, said two-layer CLC-based spectral filtering structure including first and second CLC layers, and

a plurality of pixel structures formed in said first and second CLC layers,

wherein each said pixel structure has red, blue and green subpixel structures;

wherein each red subpixel structure therein is realized by a clear (i.e. non-reflecting) region in the first CLC layer, a blue-green-band RHCP reflecting region in the second CLC layer, a clear non-reflecting region in the third CLC layer, and a blue-green band LHCP reflecting region in the fourth CLC layer,

wherein each blue subpixel structure therein is realized by a green-red band RHCP reflecting region in the first CLC layer, a clear non-reflecting region in the second CLC layer, a green-red band LHCP reflecting region in the third CLC layer, and a clear non-reflecting region in the fourth CLC layer, and

wherein each green subpixel structure therein is realized by a red-band RHCP reflecting region in the first CLC layer, a blue-band RHCP reflecting region in the second CLC layer, a red-band LHCP reflecting region in the third CLC layer, and a blue-band LHCP reflecting region in the fourth CLC layer, and

wherein an inter-subpixel "white" reflective matrix-like pattern is integrally-embodied within the spectral filtering structure, between neighboring red and blue subpixel regions by virtue of (i) the spatially-overlapping green-red band RHCP reflecting regions in the first CLC layer and the blue-green band RHCP reflecting regions in the second CLC layer, (ii) the spatially-overlapping blue-green band RHCP reflecting regions in the second CLC layer and the green-red band LHCP reflecting regions in the third CLC layer, and (iii) the spatially-overlapping green-red band LHCP reflecting regions in the third CLC layer and the blue-green band LHCP reflecting regions in the fourth CLC layer, between the red and blue

subpixel regions, and between neighboring blue and green subpixel regions by virtue of (i) the spatially-overlapping green-red band RHCP reflecting regions in the first CLC layer and the blue band RHCP reflecting regions in the second CLC layer, (ii) the spatially-overlapping blue band RHCP reflecting regions in the second CLC layer and the green-red band LHCP reflecting regions in the third CLC layer, and (iii) the spatially-overlapping green-red LHCP band reflecting regions in the third CLC layer and the blue band LHCP reflecting regions in the fourth CLC layer.

155. The method of making an inter-subpixel "white" reflective matrix-like pattern integrally-embodied within a spectral filtering structure, comprising the steps of:

- (i) forming spatially-overlapping green-red band RHCP reflecting regions in a first CLC layer and the blue-green band RHCP reflecting regions in a second CLC layer;
- (ii) forming spatially-overlapping blue-green band RHCP reflecting regions in the second CLC layer and green-red band LHCP reflecting regions in a third CLC layer; and
- (iii) forming spatially-overlapping green-red band LHCP reflecting regions in the third CLC layer and the blue-green band LHCP reflecting regions in a fourth CLC layer.

156. The method of making an inter-subpixel "white" reflective matrix-like pattern integrally-embodied within a spectral filtering structure, comprising the steps of:

- (i) the spatially-overlapping green-red band RHCP reflecting regions in a first CLC layer and the blue band RHCP reflecting regions in a second CLC layer;
- (ii) the spatially-overlapping blue band RHCP reflecting regions in the second CLC layer and green-red band LHCP reflecting regions in a third CLC layer; and
- (iii) the spatially-overlapping green-red LHCP band reflecting regions in the third CLC layer and the blue band LHCP reflecting regions in a fourth CLC layer.

157. The liquid crystal display (LCD) panel assembly comprising:

- a two-layer CLC-based spectral filtering structure; and
- a liquid crystal (LC) spatial-intensity modulation panel, said two-layer CLC-based spectral filtering structure including first and second CLC layers, and
- a plurality of pixel structures formed in said first and second CLC layers, wherein each said pixel structure has red, blue and green subpixel structures; wherein each blue subpixel structure therein is realized by a red-band RHCP reflecting region in the first CLC layer, a green-band RHCP reflecting region in the second

CLC layer, a red-band LHCP reflecting region in the third CLC layer, and a green-band LHCP reflecting region in the fourth CLC layer,

wherein each red subpixel structure therein is realized by a blue-band RHCP reflecting region in the first CLC layer, a green-band RHCP reflecting region in the second CLC layer, a blue-band LHCP reflecting region in the third CLC layer and a green-band LHCP reflecting region in the fourth CLC layer, and

wherein each green subpixel structure therein is realized by a blue-band RHCP reflecting region in the first CLC layer, a red-band RHCP reflecting region in the second CLC layer, a blue-band LHCP reflecting region in the third CLC layer, and a red-band LHCP reflecting region in the fourth CLC layer.

158. The liquid crystal display (LCD) panel assembly comprising:

a two-layer CLC-based spectral filtering structure; and

a liquid crystal (LC) spatial-intensity modulation panel, said two-layer CLC-based spectral filtering structure including first and second CLC layers, and

a plurality of pixel structures formed in said first and second CLC layers,

wherein each said pixel structure has red, blue and green subpixel structures;

wherein each blue subpixel structure therein is realized by a green-band RHCP reflecting region in the first CLC layer, a red-band RHCP reflecting region in the second CLC layer, a green-band LHCP reflecting region in the third CLC layer, and a red-band LHCP reflecting region in the fourth CLC layer,

wherein each green subpixel structure therein is realized by a green-band RHCP reflecting region in the first CLC layer, a red-band RHCP reflecting region in the second CLC layer, a blue-band LHCP reflecting region in the third CLC layer and a red-band LHCP reflecting region in the fourth CLC layer, and

wherein each red subpixel structure therein is realized by a blue-band RHCP reflecting region in the first CLC layer, a green-band RHCP reflecting region in the second CLC layer, a blue-band LHCP reflecting region in the third CLC layer, and a green-band LHCP reflecting region in the fourth CLC layer.

159. The CLC-based spectral filtering device for producing spectrally filtered patterns of linearly polarized light from a source of white unpolarized light, comprising:

a two-layer CLC-based spectral filtering structure, including first and second CLC layers, and

a plurality of pixel structures formed in said first and second CLC layers,  
wherein each said pixel structure has red, blue and green subpixel structures;  
wherein each red subpixel structure therein is realized by a clear (non reflecting)  
region in the first CLC layer and a green-blue band reflecting region in the second CLC  
layer,  
wherein each green subpixel structure therein is realized by a red band reflecting  
region in the first CLC layer and a blue reflecting region in the second CLC layer,  
wherein each blue subpixel structure therein is realized by a red-green band reflecting  
region in the first CLC layer and a clear (non-reflecting) region in the second CLC layer, and  
wherein a green-blue band reflecting pattern and quarter-wave retardation surface  
thereover are provided beneath the first CLC layer in order to realize the broad-band inter-  
subpixel "white" reflective matrix-like pattern between neighboring subpixel regions.

160. The CLC-based spectral filtering device for producing spectrally filtered patterns of  
linearly polarized light from a source of white unpolarized light, comprising:

a two-layer CLC-based spectral filtering structure, including first and second CLC  
layers, and

a plurality of pixel structures formed in said first and second CLC layers,  
wherein each said pixel structure has red, blue and green subpixel structures;  
wherein each blue subpixel structure therein is realized by a red-band reflecting  
region in the first (i.e. lower) CLC layer and a green band reflecting region in the second  
CLC layer,  
wherein each green subpixel structure therein is realized by a red band reflecting  
region in the first CLC layer and a blue band reflecting region in the second CLC layer,  
wherein each red subpixel structure therein is realized by a green band reflecting  
region in the first CLC layer and a blue-band reflecting region in the second CLC layer, and  
wherein a green-blue band reflecting pattern and quarter-wave retardation surface  
thereover are provided beneath said first CLC layer in order to realize the broad-band inter-  
subpixel "white" reflective wherein matrix-like pattern between neighboring subpixel  
regions.

161. The CLC-based spectral filtering device for producing spectrally filtered patterns of  
linearly polarized light from a source of white unpolarized light, comprising:

a two-layer CLC-based spectral filtering structure, including first and second CLC  
layers, and

a plurality of pixel structures formed in said first and second CLC layers,  
wherein each said pixel structure has red, blue and green subpixel structures;  
wherein each red subpixel structure therein is realized by a clear (non-reflecting) region in the first CLC layer and a blue-green band reflecting region in the second CLC layer,  
wherein each blue subpixel structure therein is realized by a green-red band reflecting region in the first CLC layer and a clear (non-reflecting) region in the second CLC layer,  
wherein each green subpixel structure therein is realized by a red band reflecting region in the first CLC layer and a blue-band reflecting region in the second CLC layer, and  
wherein a broad-band reflecting pattern and quarter-wave retardation surface thereover are provided beneath said first CLC layer in order to realize the broad-band inter-subpixel "white" reflective matrix-like pattern between neighboring subpixel regions.

162. The reflective color filter comprising:

two layers of cholesteric liquid crystals having two different center wavelengths and bandwidths per layer are stacked for providing colored light for displays.

A reflective cholesteric liquid crystal (CLC) color filter comprising only two different color portions in each CLC layer.

163. The reflective color filter made from cholesteric liquid crystals that transmits red-green and blue light from different pixels with a two layer configuration, where each layer has only two reflection bands.

164. The spectral filter structure comprising:

one layer of cholesteric liquid crystal materials with each side of the layer reflecting a different band of wavelengths around a different central wavelength.

165. The method making a reflective CLC filter comprising the steps of:

(a) exposing one half of a layer of CLC material to UV light which is absorbed by attenuation in the cholesteric liquid crystal materials by the time it is one half way through the layer, thus polymerizing one half of the layer.

166. The method of making a reflective cholesteric liquid crystal color filter comprising:

(a) reflecting two different bandwidths of light in the top portion of the layer, and one bandwidth of light in the bottom portion of the layer.

167. The method of making a reflective CLC filter comprising the steps of:  
stacking several different polymerized states of cholesteric liquid crystal materials in a single layer of CLC material.
168. The method of claim 167, which further comprises:  
affixing a quarter-wave plate integral to said single layer of CLC material.
169. The method of making a reflective CLC filter comprising the steps of: wherein  
(a) stacking multiple portions of polymerized cholesteric liquid crystal materials with different properties in each portion in a single layer of cholesteric liquid crystal material.
170. Material recipes for creating the reflective color filter made from the cholesteric liquid crystal material that transmits red-green and blue from different subpixels with a two-layer configuration, each of which has only two reflection bandwidths.
171. The method of making a reflective color filter comprising the steps of:  
stacking two CLC layers together, wherein each said CLC layer has only two reflection bandwidths so as to form subpixels capable of transmitting red-green and blue light therethrough.
172. The image display for producing images having three primary colors comprising:  
an array of pixels formed within two layers of reflective material and providing reflective-type spectral filters for spectrally filtering incident light on a subpixel by subpixel basis; and  
a matrix structure formed about said pixels by the overlapping of said reflective-type spectral filters so as to reflect all light falling incident thereupon.



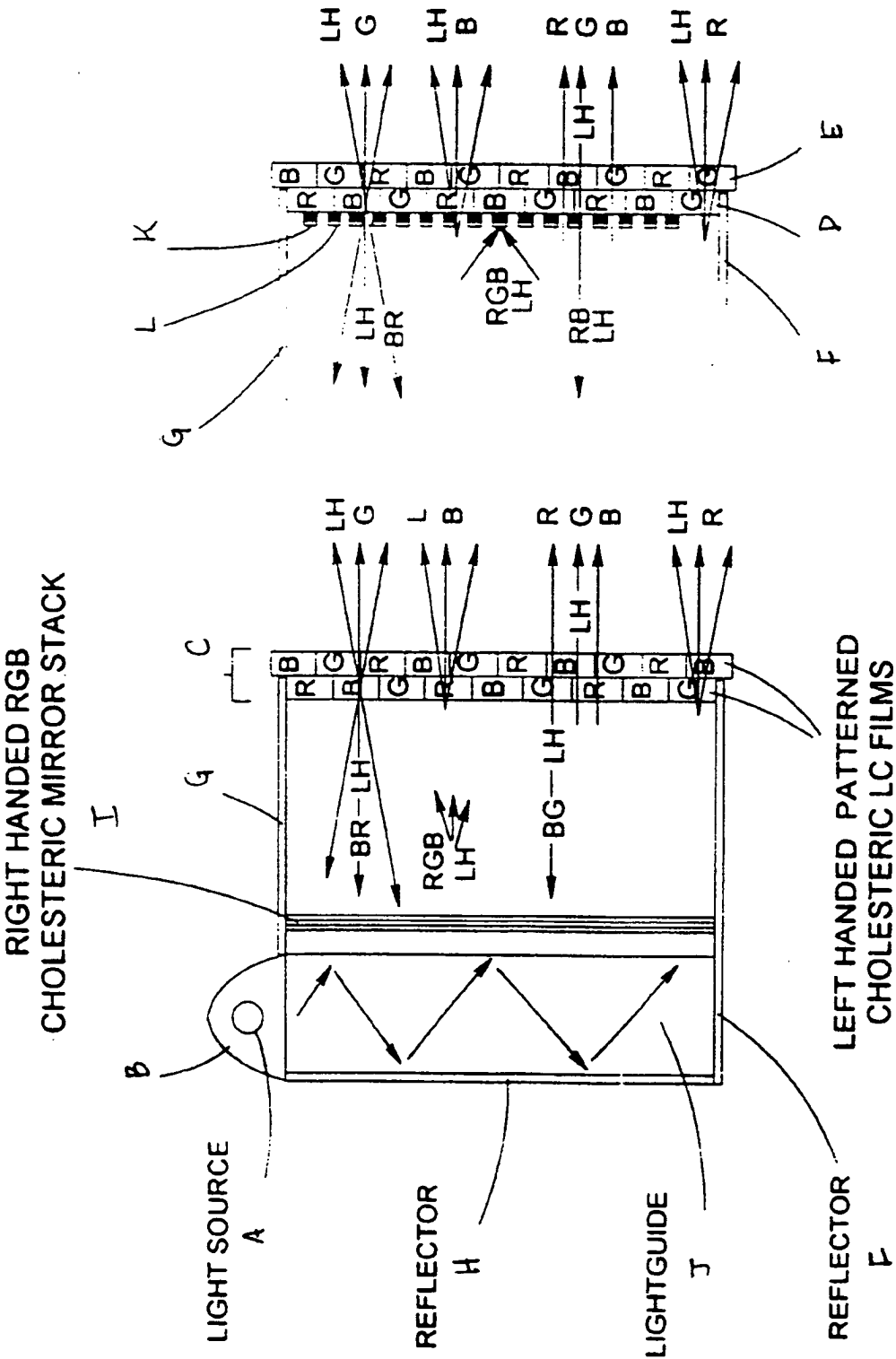


FIG. 1B (PRIOR ART)

FIG. 1A (PRIOR ART)

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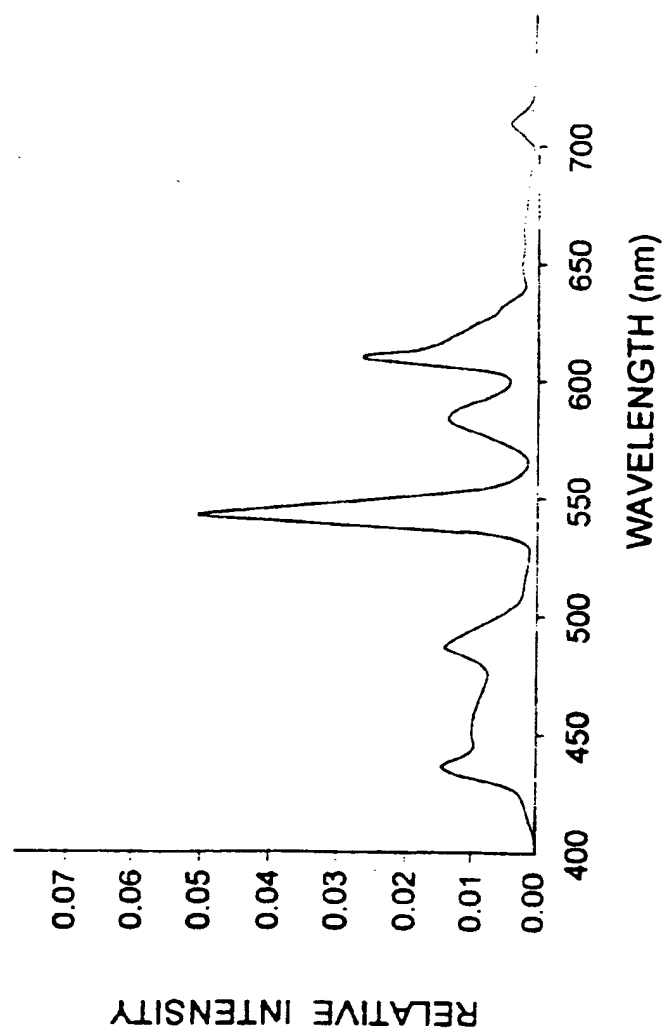


FIG. 1C (PRIOR ART)

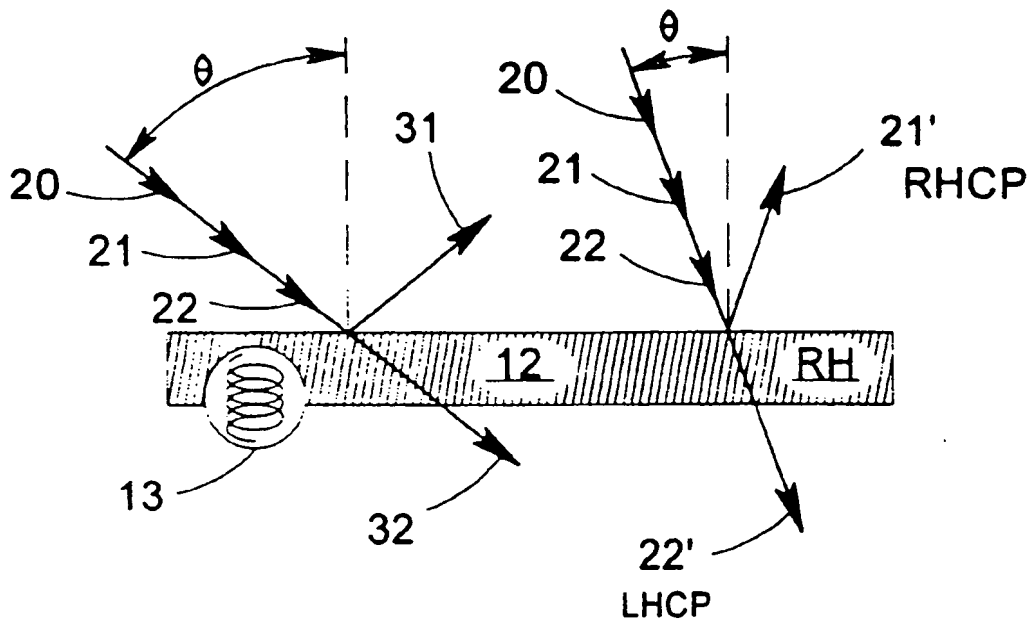


FIG. 1D (PRIOR ART)

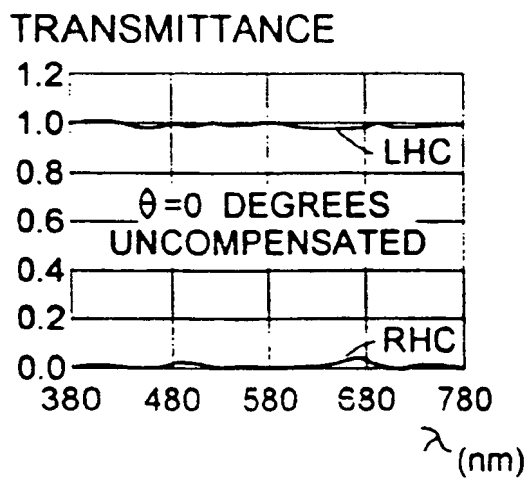


FIG. 1E (PRIOR ART)

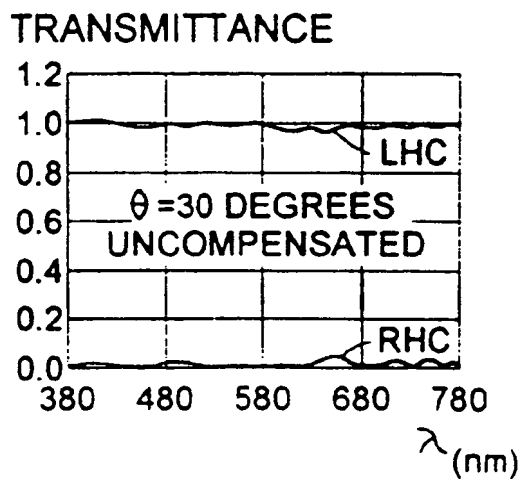


FIG. 1F (PRIOR ART)

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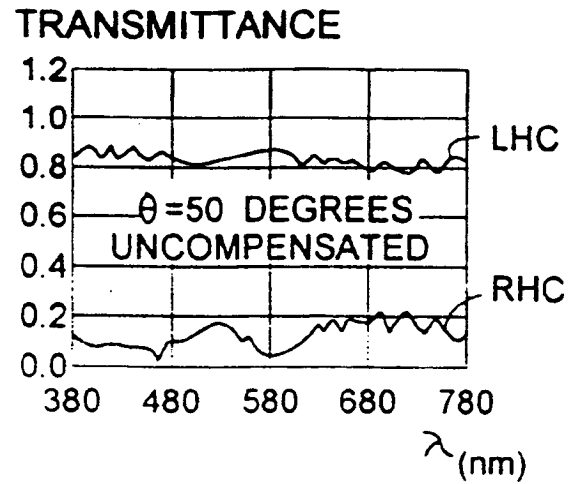


FIG. 1G (PRIOR ART)

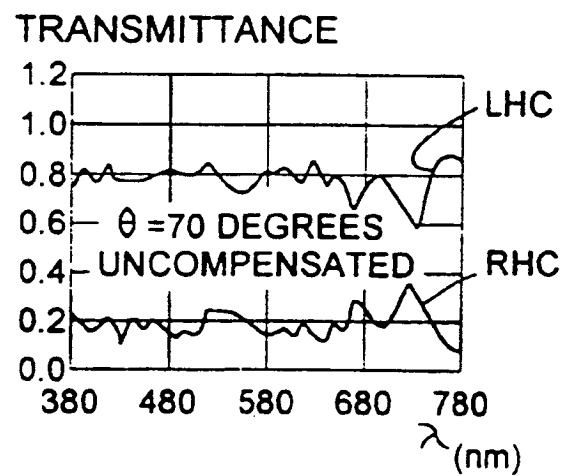
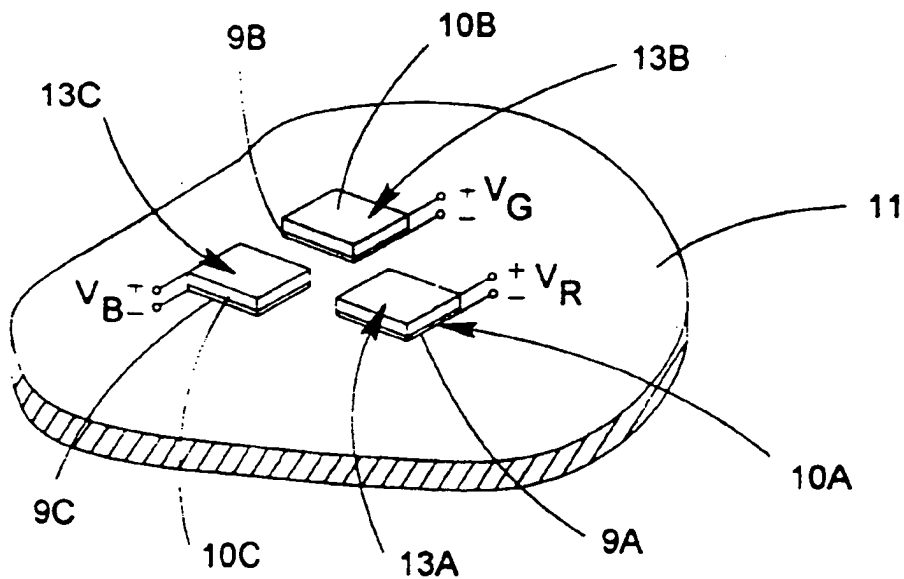
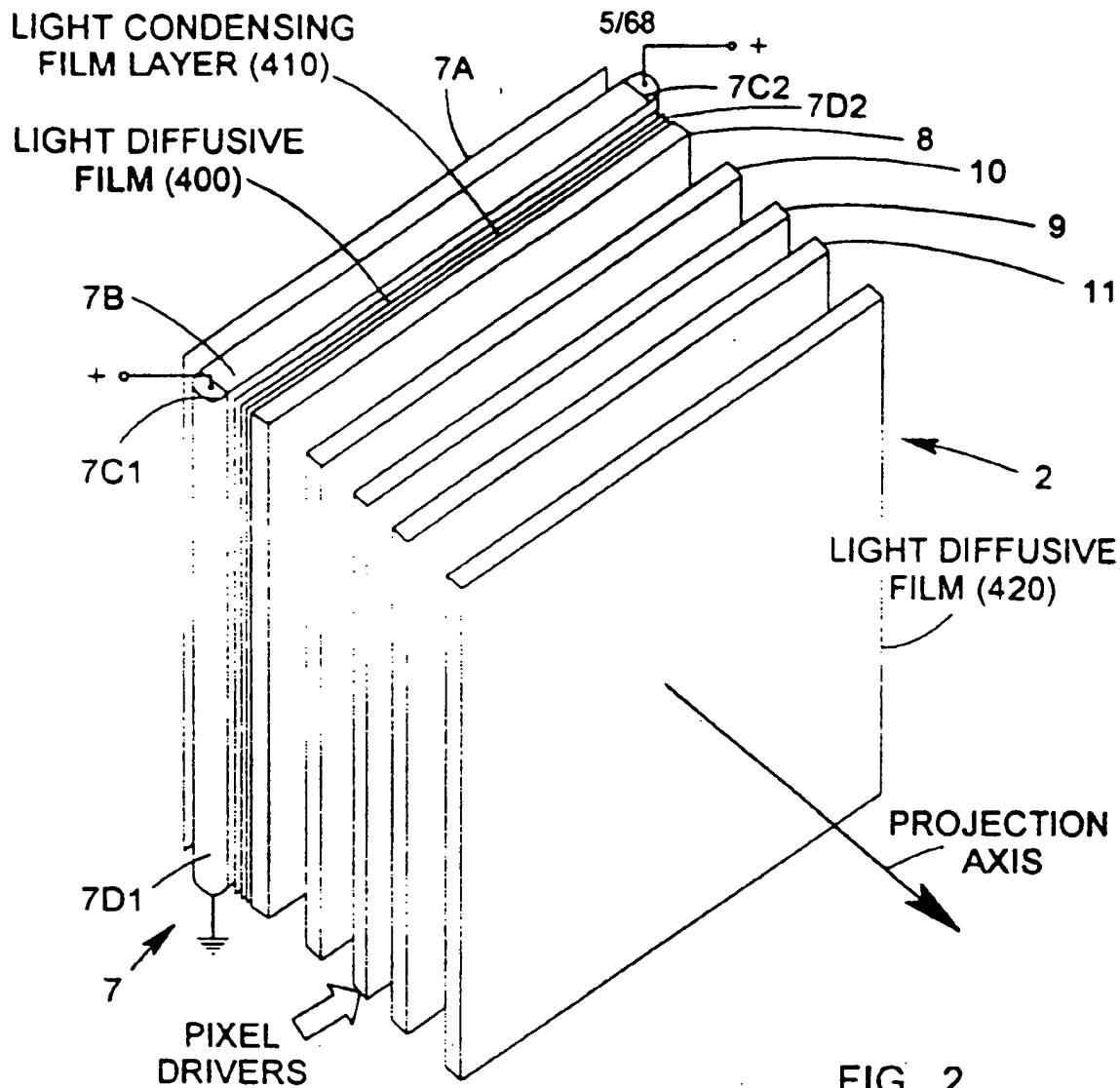


FIG. 1H (PRIOR ART)



# Super-Bright™ Color LCD

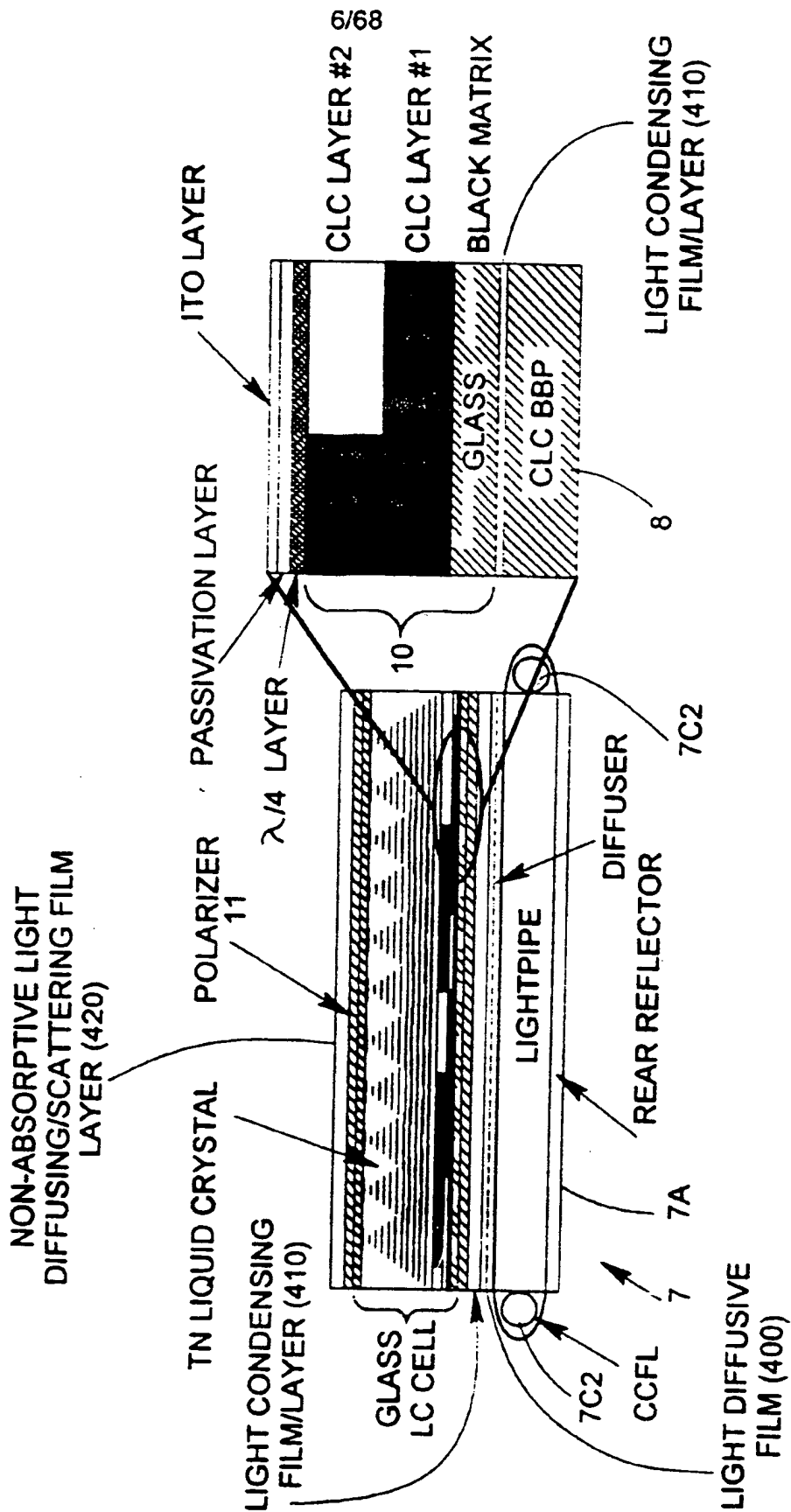
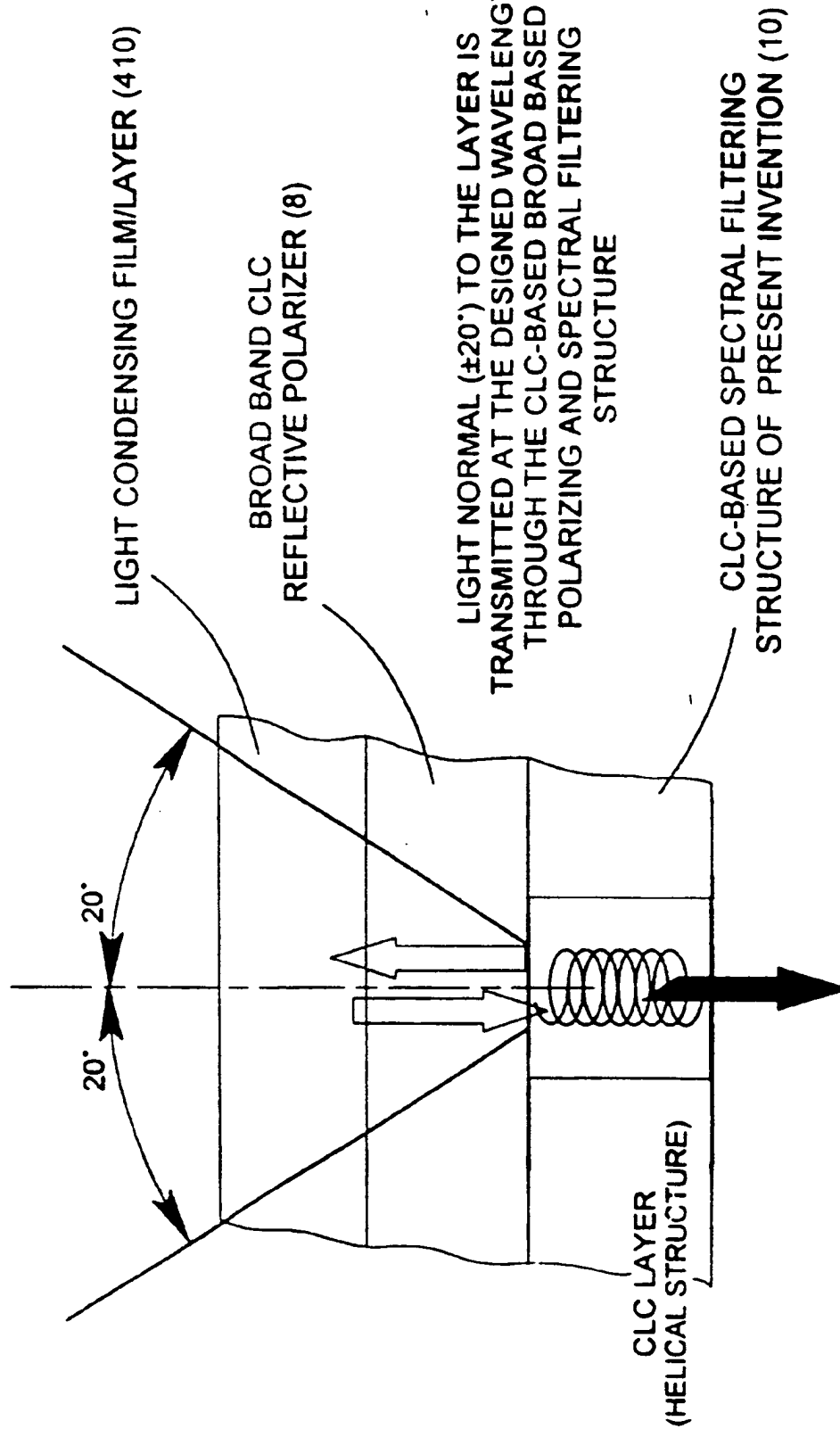


FIG. 2B

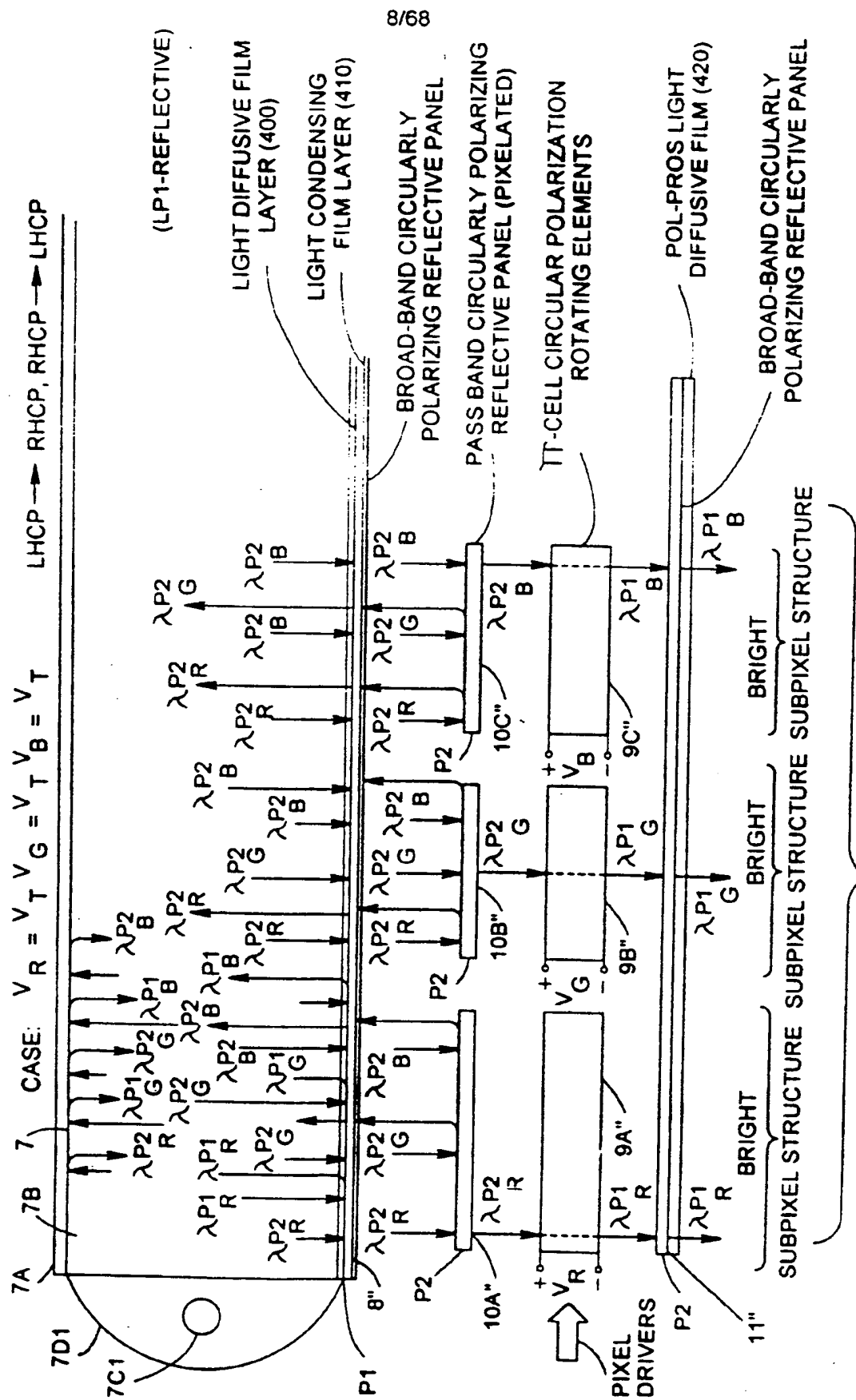
FIG. 2B1

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LIGHT NORMAL ( $\pm 20^\circ$ ) TO THE LAYER IS TRANSMITTED AT THE DESIGNED WAVELENGTH THROUGH THE CLC-BASED BROAD BASED POLARIZING AND SPECTRAL FILTERING STRUCTURE

FIG. 2B2



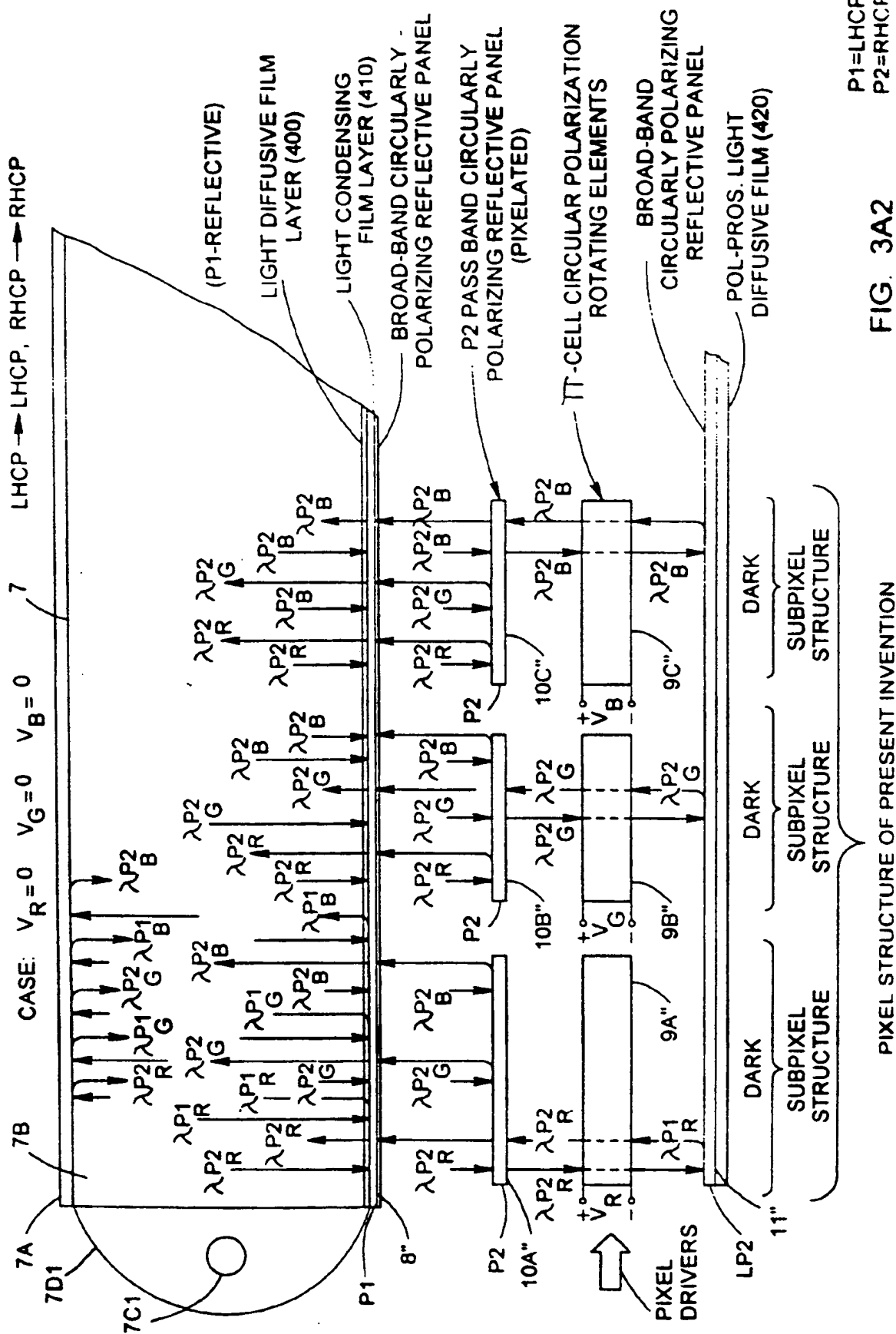
P1=LHCP  
P2=RHCP

**FIG. 3A1**

## PIXEL STRUCTURE OF PRESENT INVENTION



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**FIG. 3A2**

P1=LHCP  
P2=RHCP

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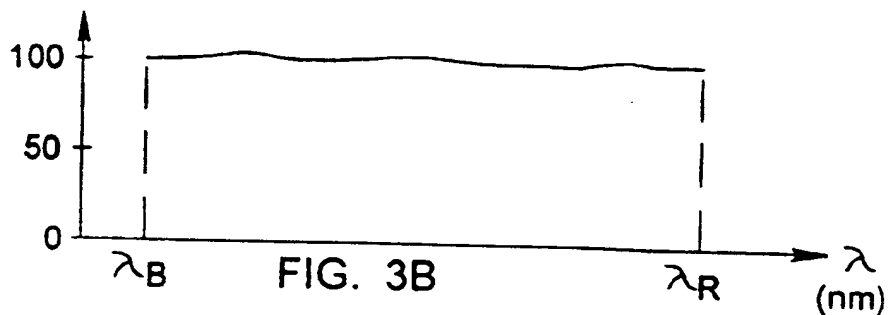
REFLECTION  
AT LHCP  
%

FIG. 3B

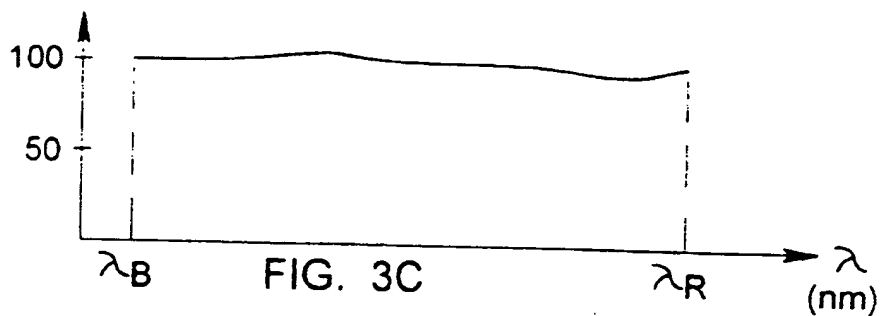
REFLECTION  
AT RHCP  
%

FIG. 3C

REFLECTION  
AT RHCP  
%

(BLUE)

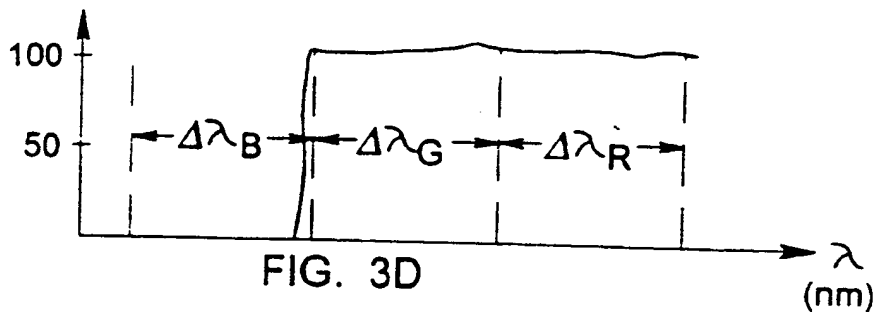


FIG. 3D

REFLECTION  
AT RHCP  
%

(GREEN)

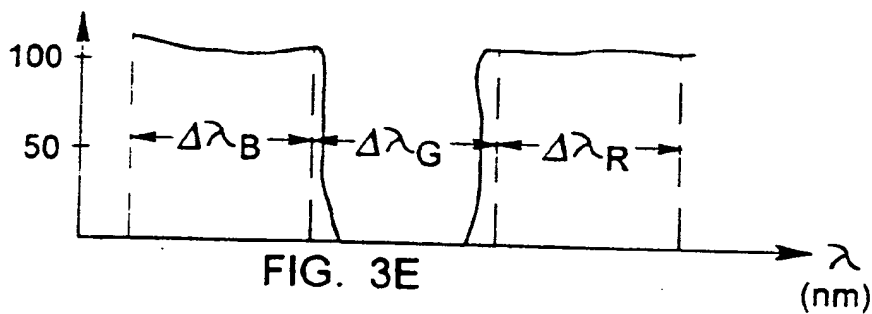


FIG. 3E

REFLECTION  
AT RHCP  
%

(RED)

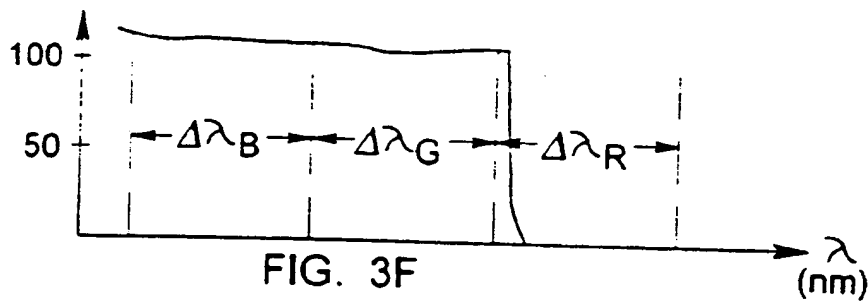


FIG. 3F

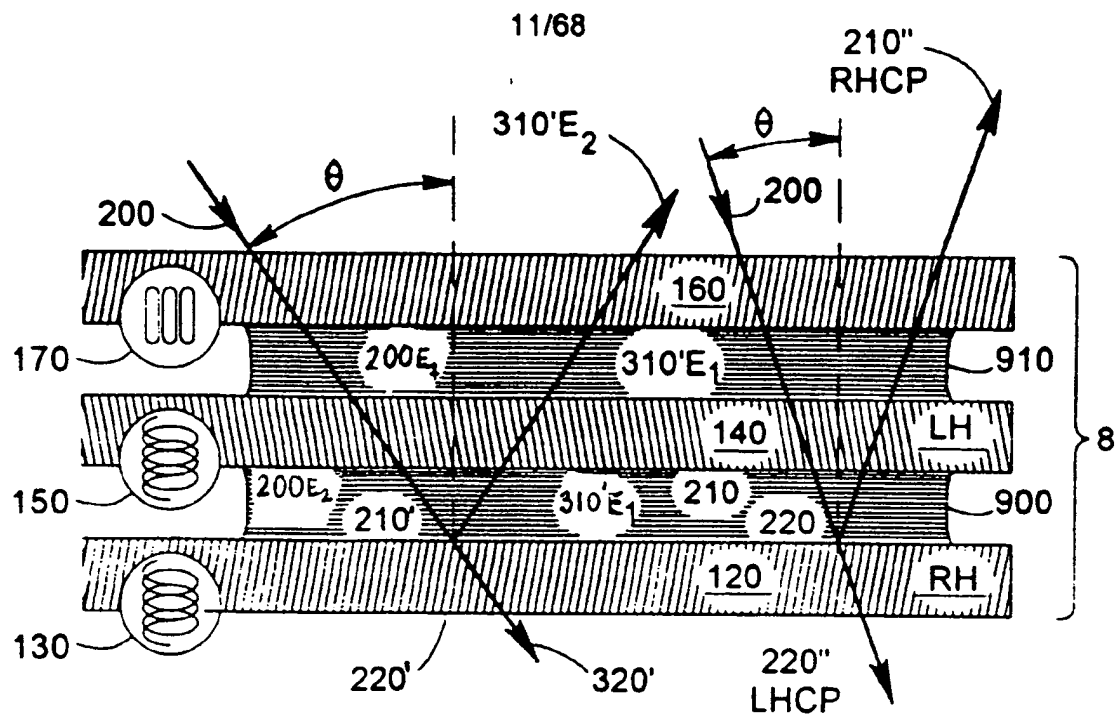


FIG. 4

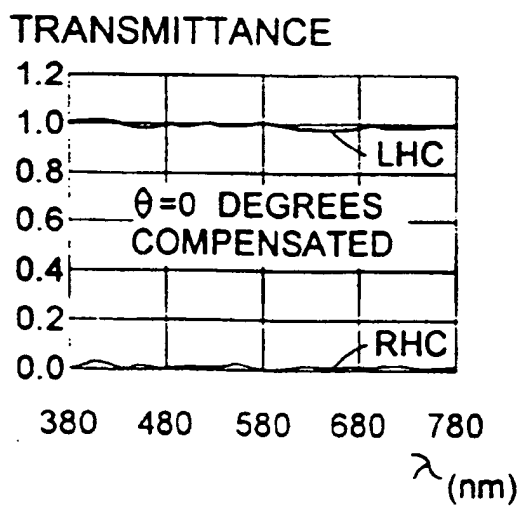


FIG. 4A

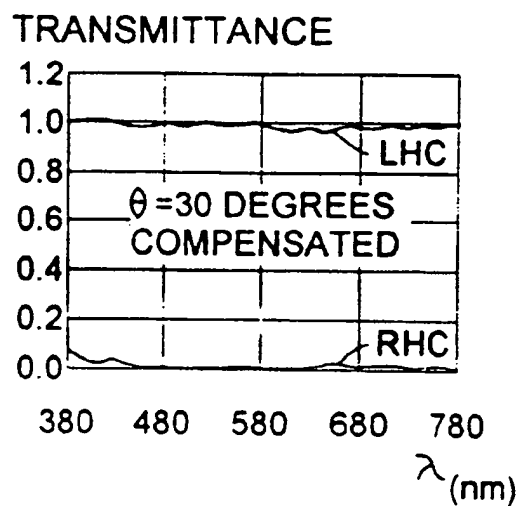


FIG. 4B

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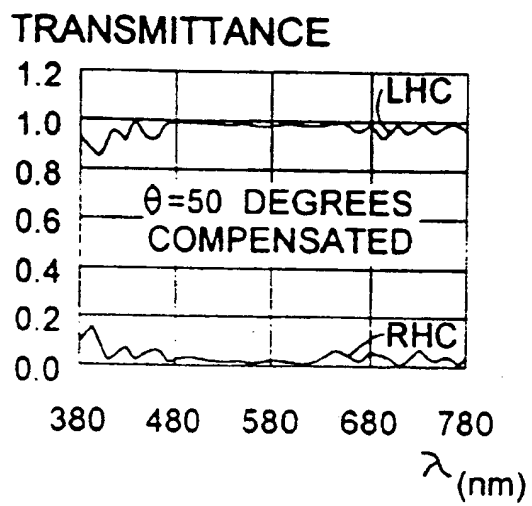


FIG. 4C

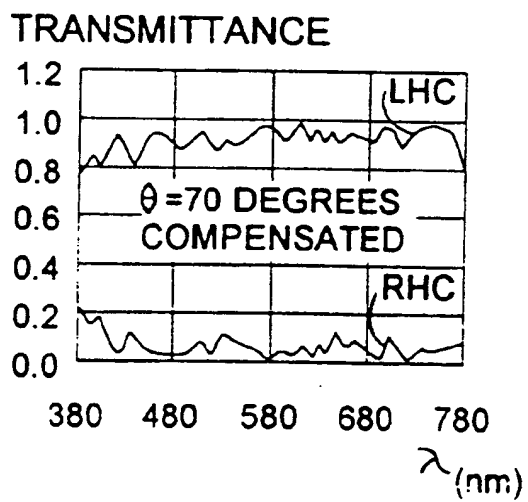
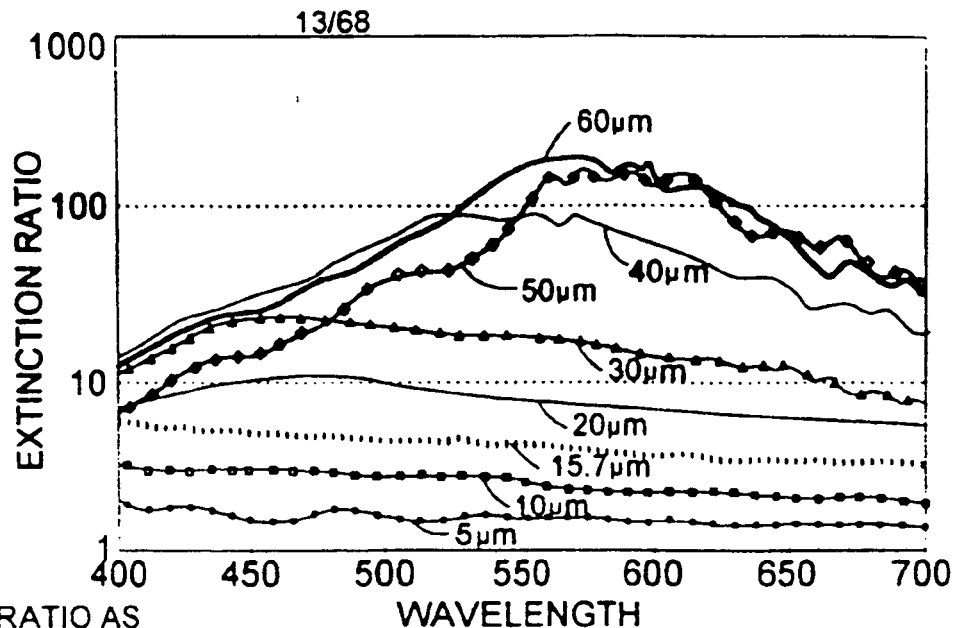


FIG. 4D



EXTINCTION RATIO AS  
A FUNCTION OF FILM  
THICKNESS

FIG. 4E

COLOR TEMPERATURE AS  
A FUNCTION OF ANGLE OF  
INCIDENCE FOR DIFFERENT  
FILM THICKNESS AND  $\Delta n = 0.15$ .

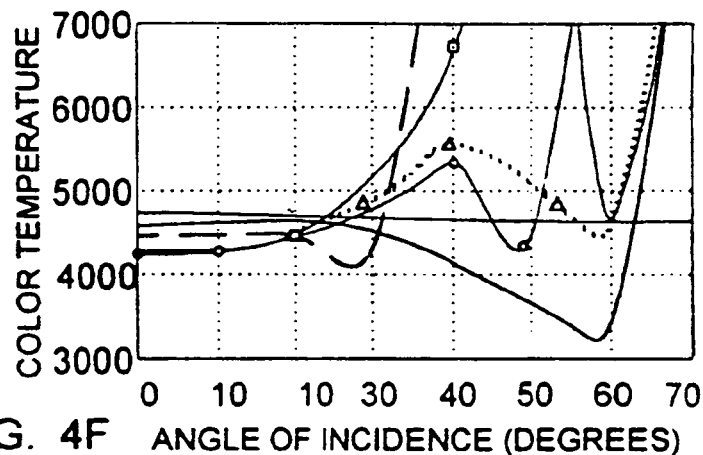


FIG. 4F

$\Delta n = 0.2$ , MUCH IMPROVED  
COLOR TEMPERATURE  
DEPENDENCE.

○, = EXPERIMENTAL DATA,  
SOLID LINE-SIMULATION. SIDE  
B (FACING UP) HAS MUCH LESS  
COLOR TEMPERATURE CHANGE  
WITH ANGLE

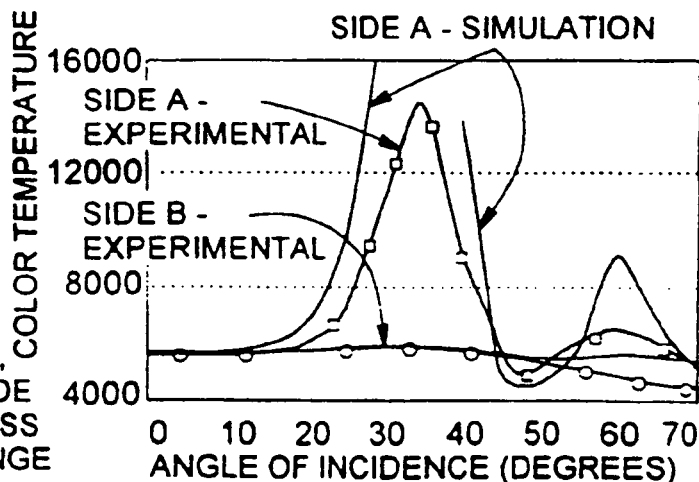
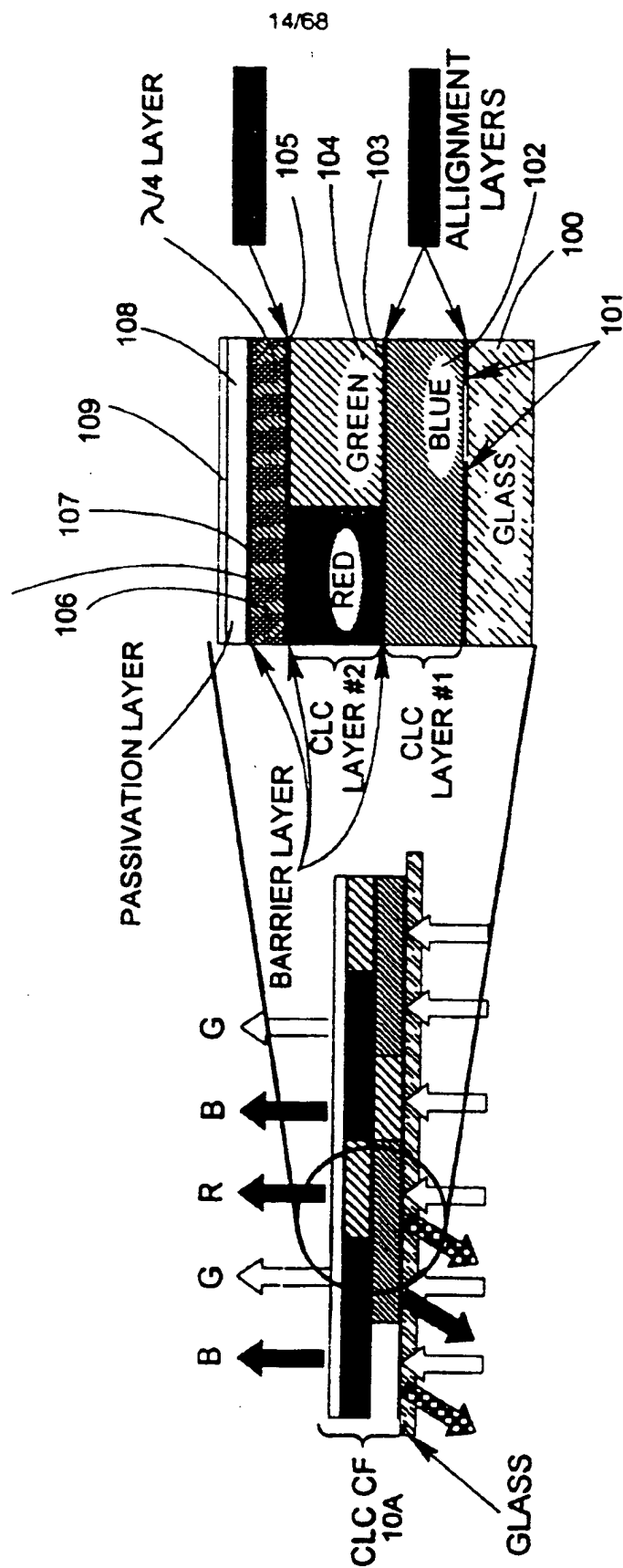


FIG. 4G

**THIS LAYER IS NOT USED WITH  
CIRCULARLY POLARIZING SPATIAL  
INTENSITY MODULATION STRUCTURES**



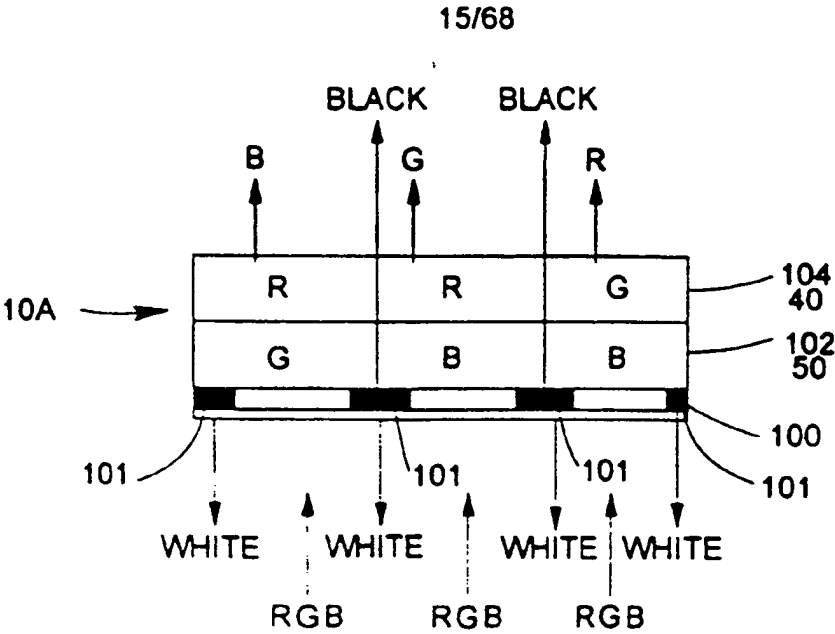


FIG. 5B1

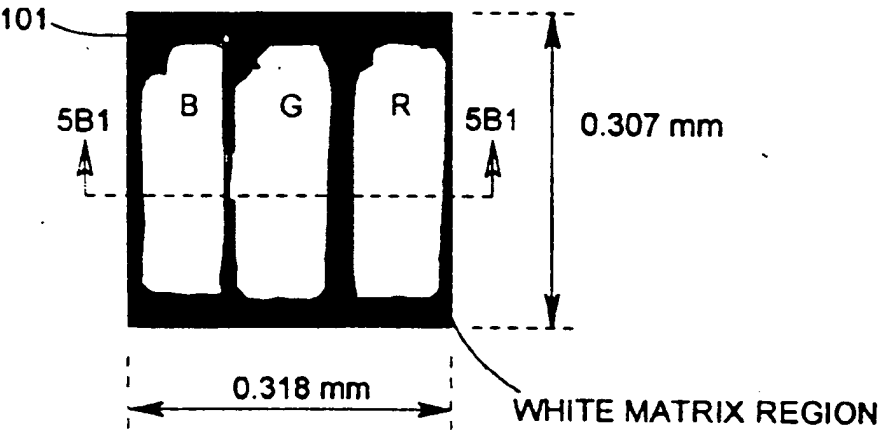


FIG. 5B2

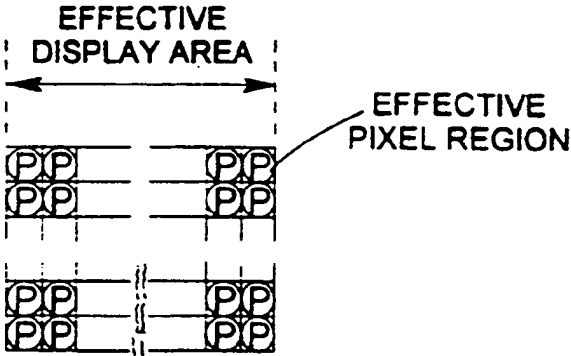


FIG. 5C

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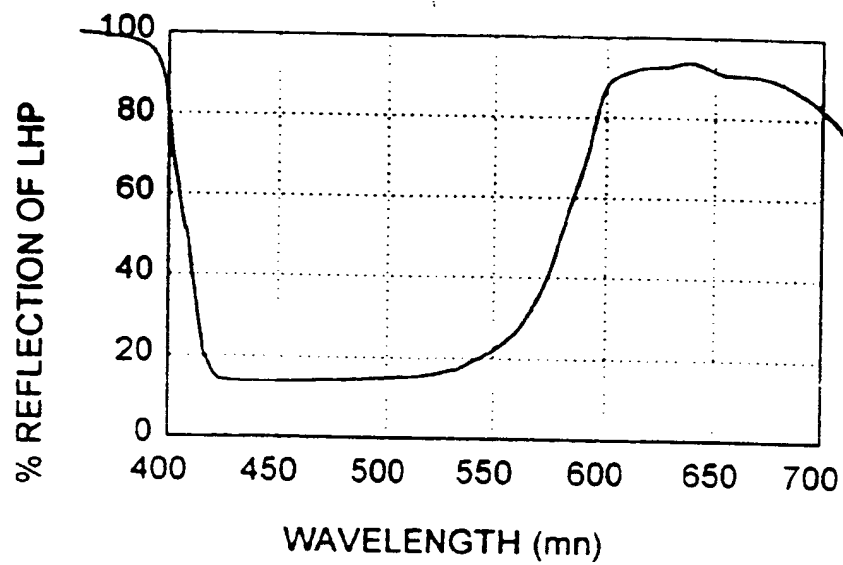


FIG. 6A

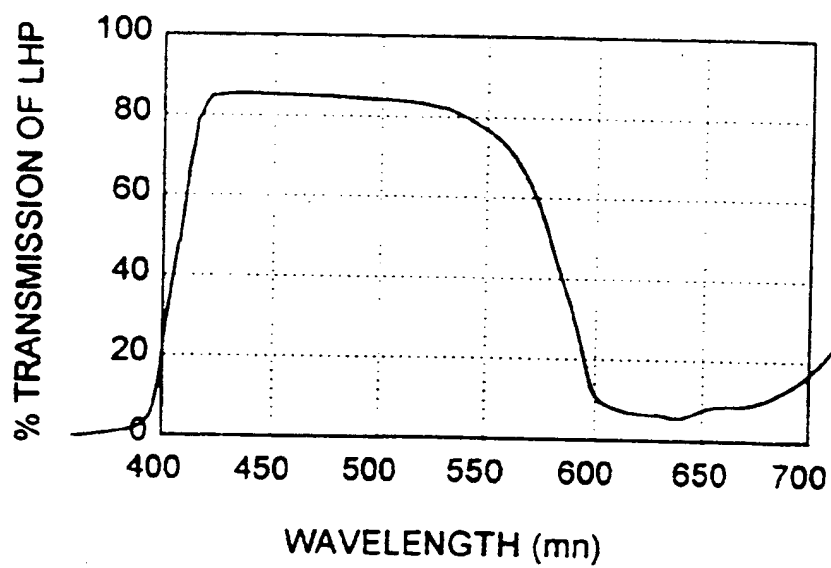


FIG. 6B



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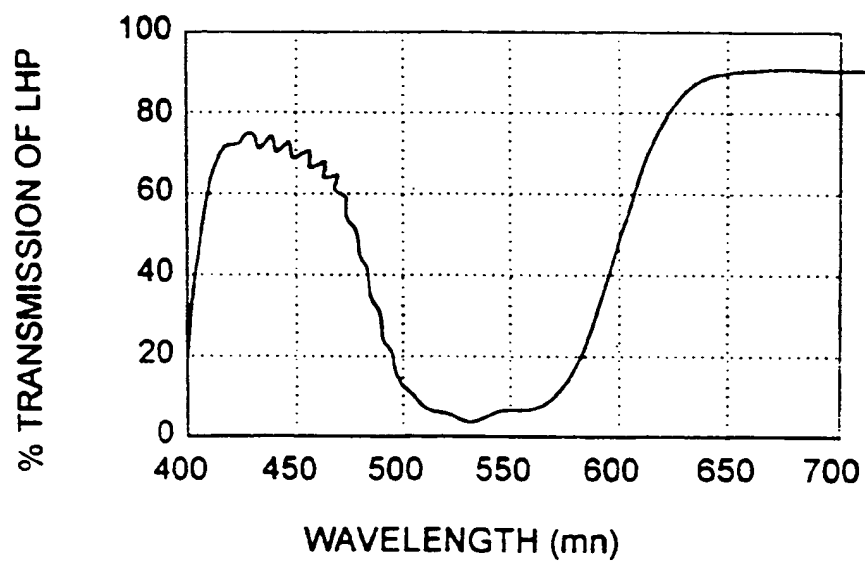
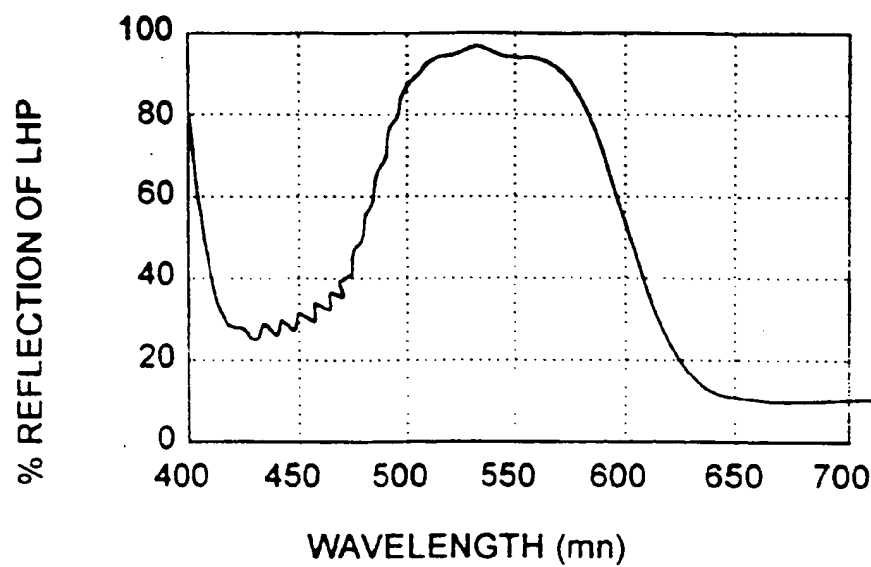


FIG. 6D

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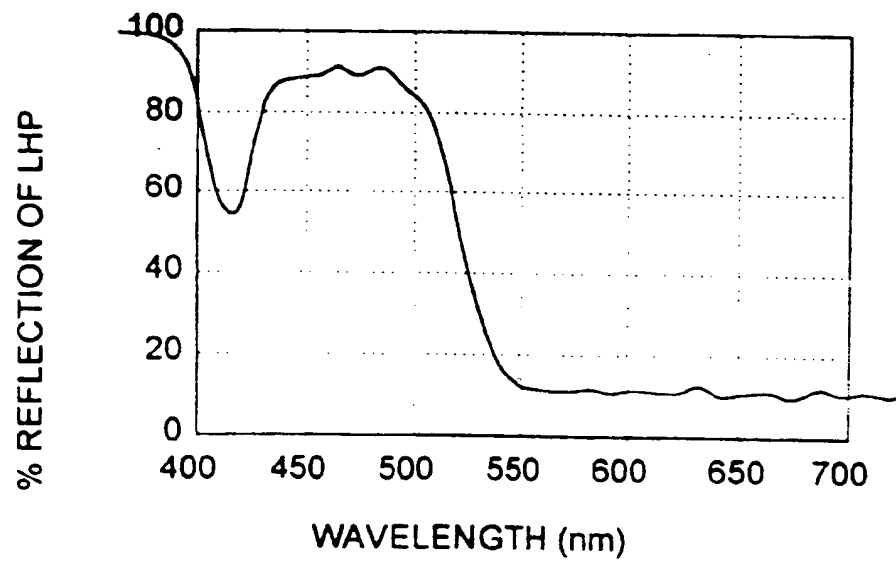


FIG. 6E

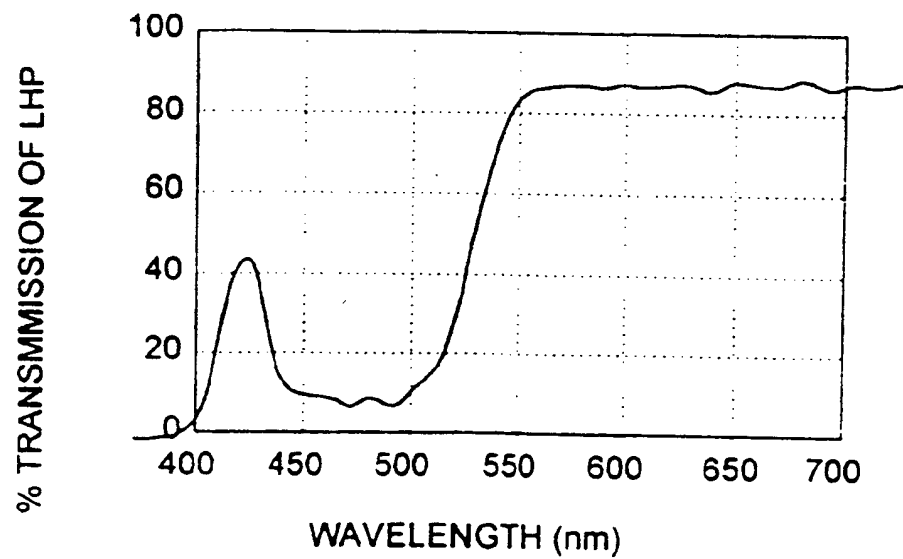


FIG. 6F

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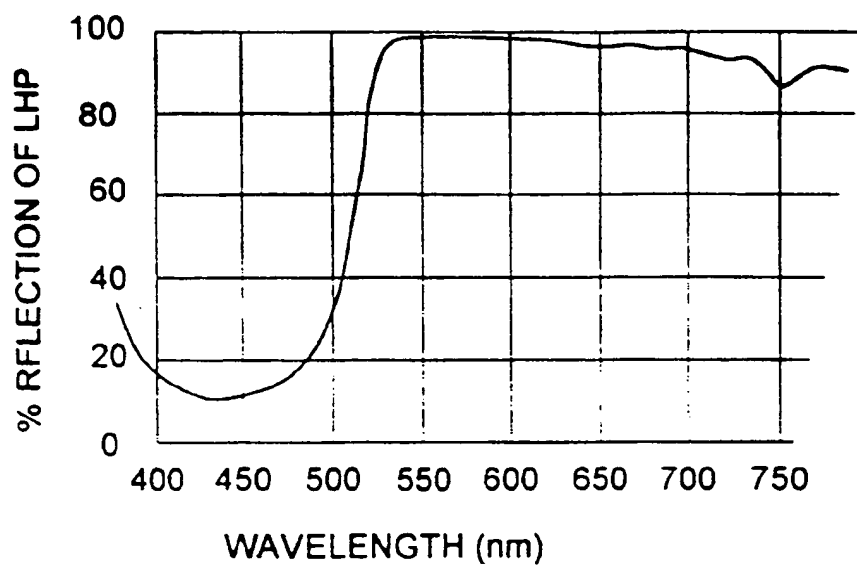


FIG. 6G

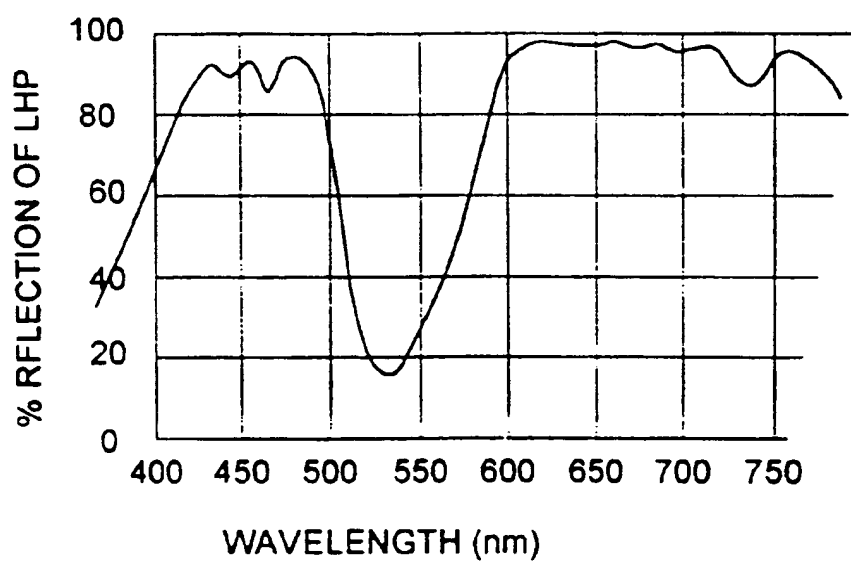


FIG. 6H

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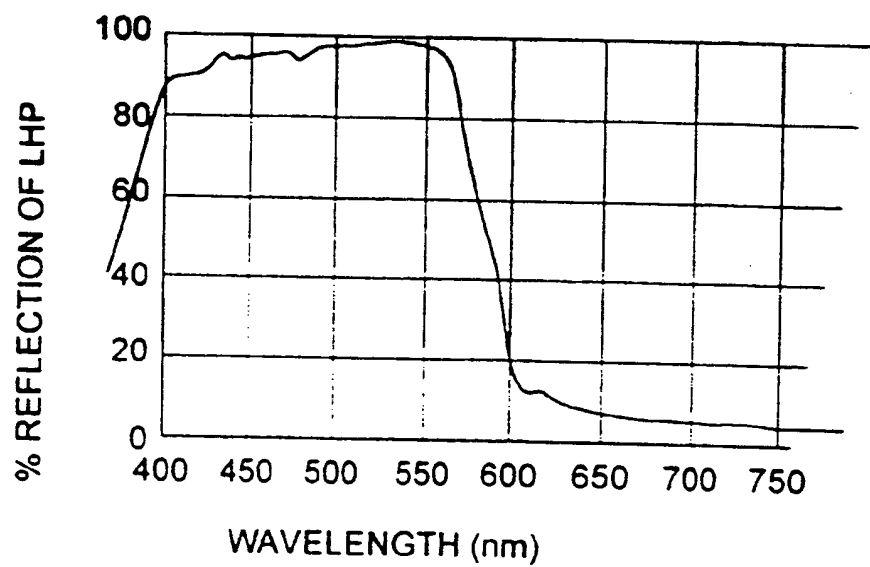


FIG. 6I

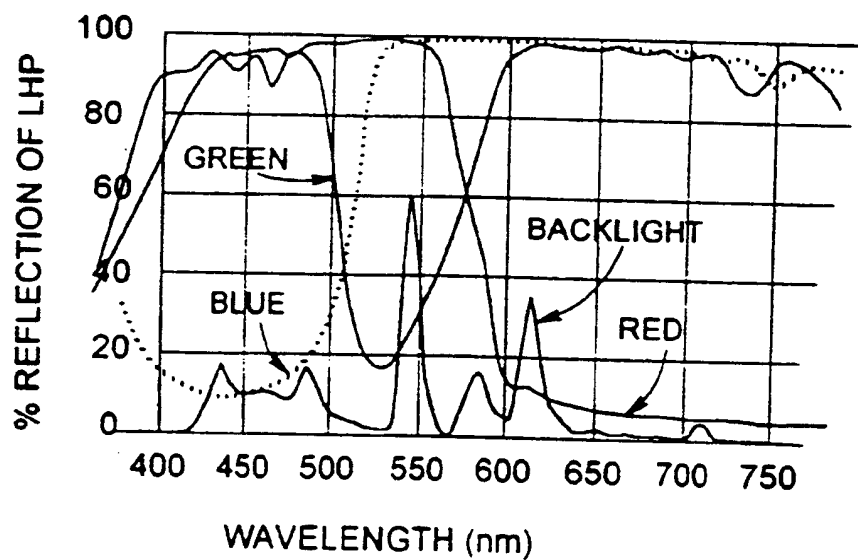


FIG. 6J

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"COLOR PURITY" IS DEFINED ON THE CHROMATICITY DIAGRAM BELOW. WE'LL USE THE FOLLOWING EXAMPLE TO EXPLAIN THE DEFINITION.

WE NEED TO MEASURE THE COLOR COORDINATES (CC) OF THE LIGHT SOURCE, C IN OUR CASE. WE MEASURE THE SAMPLE'S CC, B IN OUR CASE. WE DRAW A STRAIGHT LINE FROM C TO B AND EXTEND IT BEYOND THE CC OF THE SAMPLE UNTIL IT INTERSECTS WITH THE CHROMATICITY DIAGRAM BOUNDARY, AT I IN OUR CASE. COLOR PURITY IN % IS DEFINED AS

$$\text{COLOR PURITY} = 100 \frac{CB}{CI}$$

WHERE CB & CI ARE THE RESPECTIVE LENGTHS OF THE CORRESPONDING SEGMENTS. WHEN THE SAMPLE'S CC LIE ON THE CHROMATICITY DIAGRAM BOUNDARY ITS COLOR PURITY IS 100%.

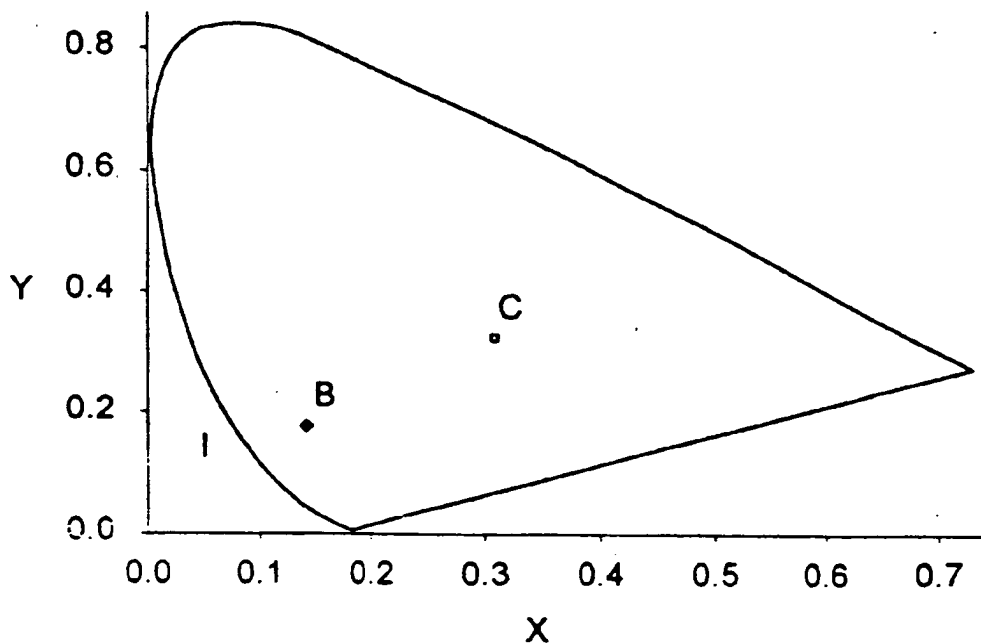


FIG. 7A

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**"COLOR COORDINATES (CC)"**

THE BLACK SQUARE (C) INDICATE THE CC OF A STANDARD LIGHT SOURCE (C SOURCE) FOR WHICH THE CC WERE CALCULATED. THE SOLID DIAMONDS INDICATE THE CC OF EACH OF THE RGB PIXELS. IN THIS CALCULATION WE USED THE TRANSMISSION DATA (OF PERPENDICULAR INCIDENT LIGHT) FOR EACH COLOR PIXEL IN ORDER TO CALCULATE ITS CC. THE SOLID LINE TRIANGLE INDICATED THE EXTENT OF COLOR GAMUT OF OUR RGB PIXELS.

SOLID CIRCLES ARE THE CC FOR A TYPICAL CONVENTIONAL ABSORPTIVE COLOR FILTERS. THEIR COLOR GAMUT (BROKEN LINE TRIANGLE) IS SMALLER THAN OUR COLOR GAMUT.

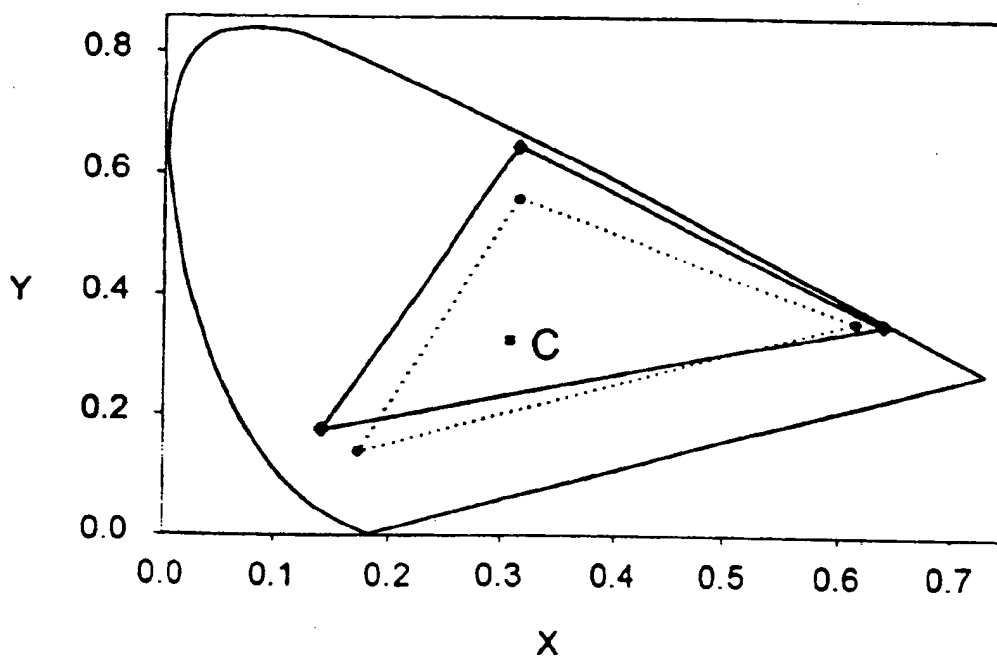


FIG. 7B

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**"EXTINCTION"**

**EXTINCTION CURVES ARE THE RATIO OF THE TRANSMISSION OF A PIXEL IN ITS BRIGHT-STATE TO THE TRANSMISSION IN THE DARK-STATE.**

$$E(\lambda) = \frac{T_{\text{BRIGHT\_STATE}}(\lambda)}{T_{\text{DARK\_STATE}}(\lambda)}$$

IT'S A MEASURE OF HOW MUCH CONTRAST WE MAY EXPECT FROM A TWISTED NEMATIC DISPLAY USING SPECTRAL FILTERS OF PRESENT INVENTION

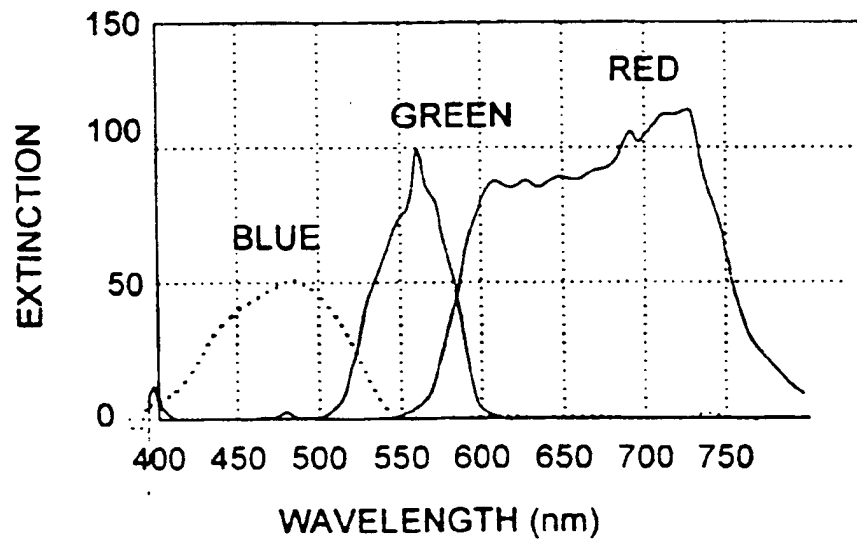


FIG. 7C

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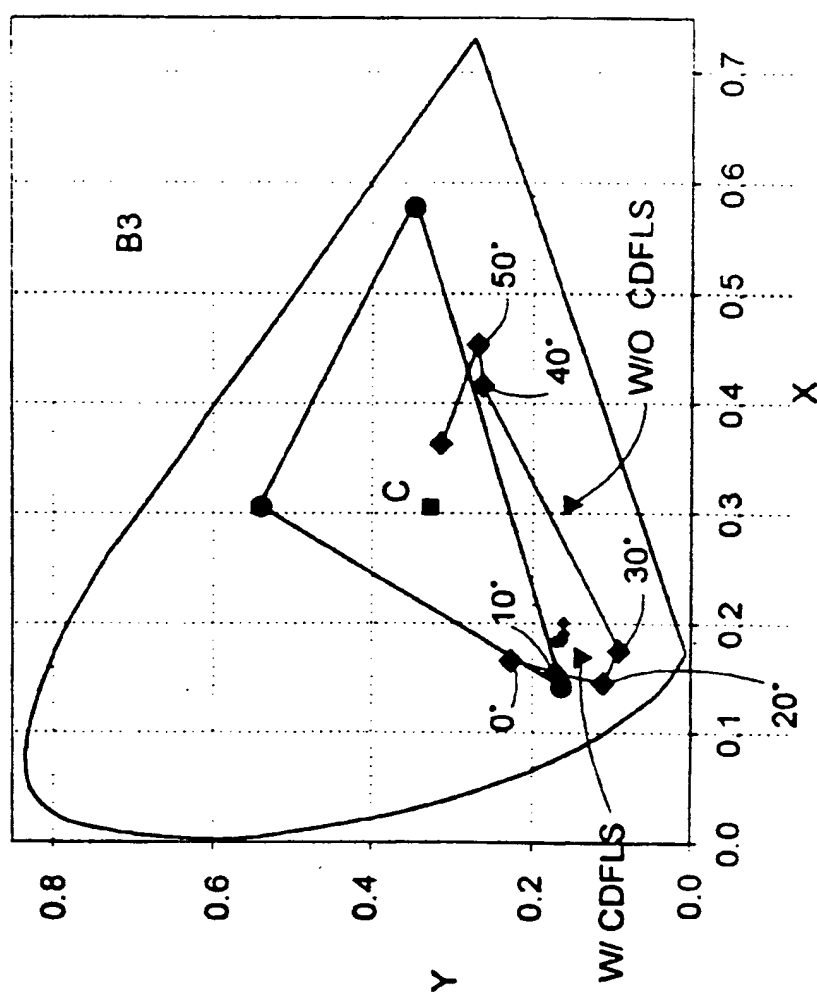


FIG. 7D1



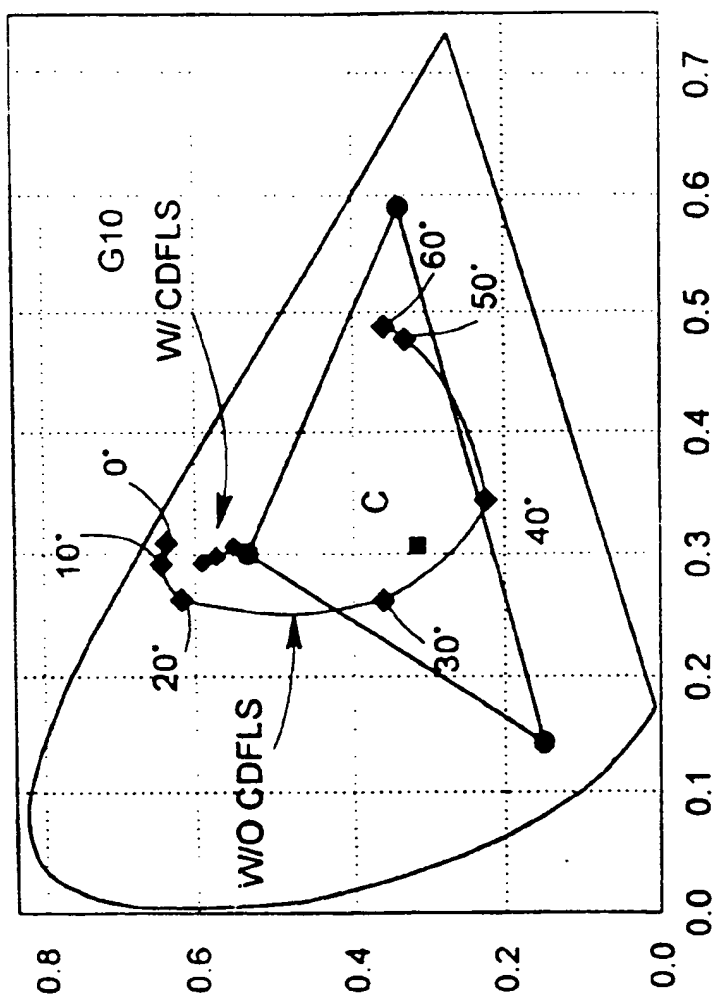


FIG. 7D2

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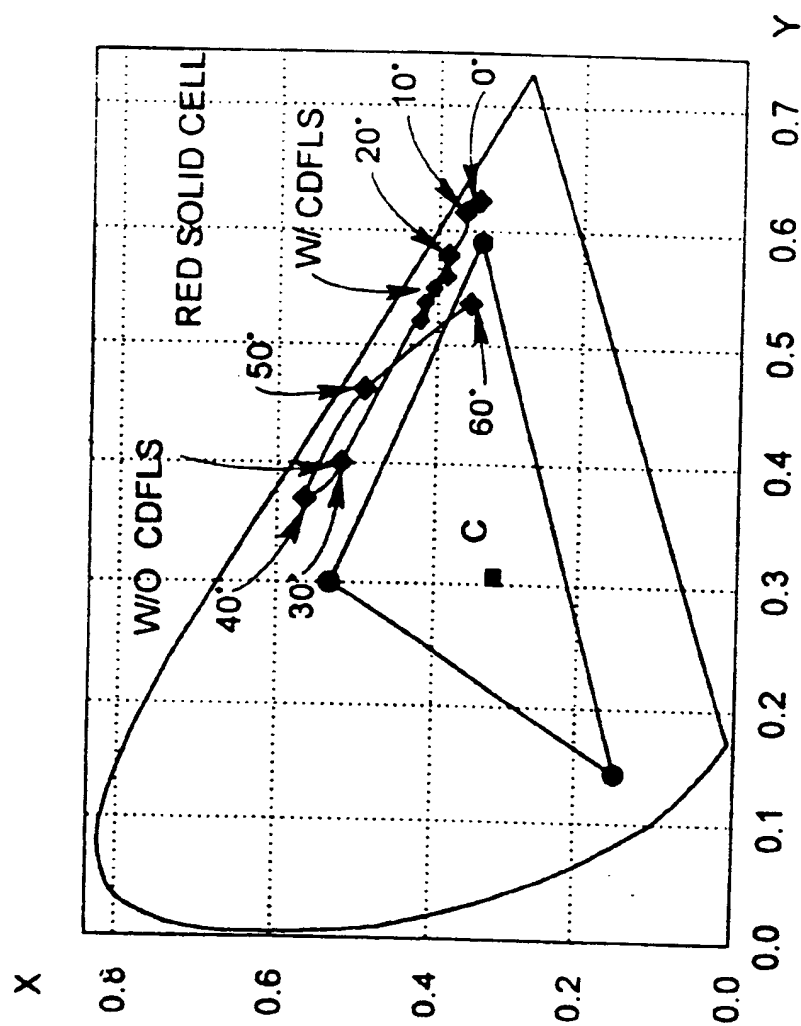


FIG. 7D3

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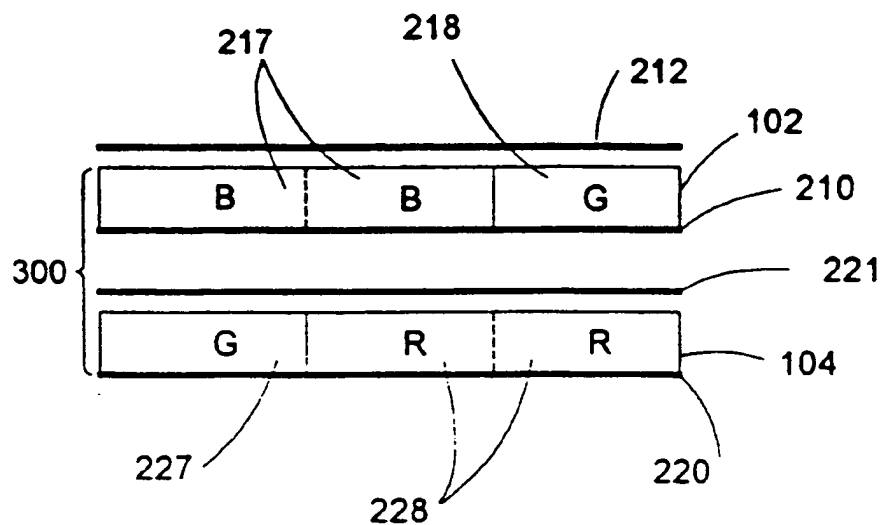


FIG. 8A

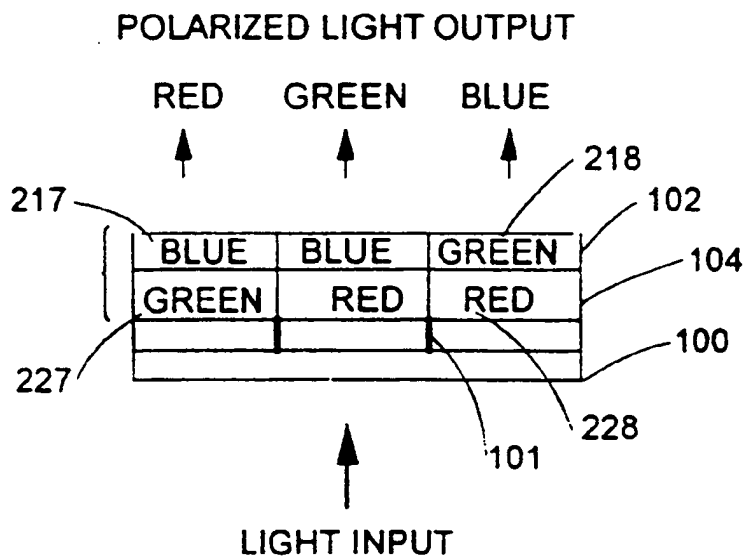


FIG. 8B

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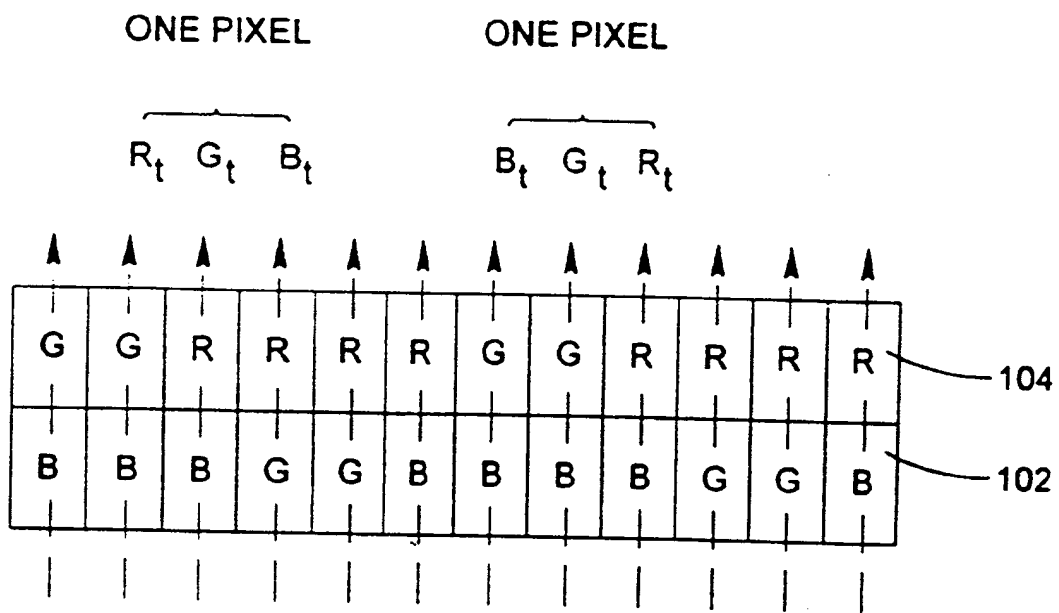


FIG. 8C

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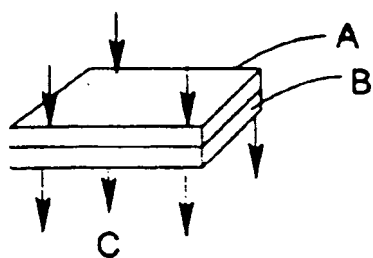


FIG. 8D1

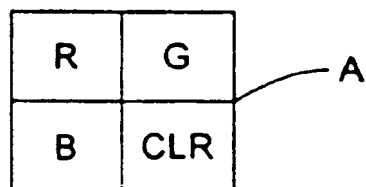


FIG. 8D2

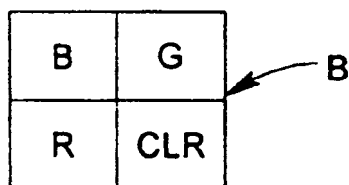


FIG. 8D3

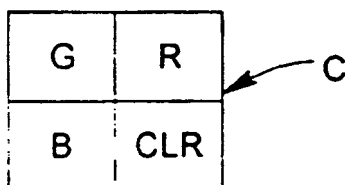


FIG. 8D4

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STEP	PROCESS	TARGET THICKNESS ( $\mu\text{m}$ )	METHOD	COMMENTS
1	CUT GLASS WITH BLACK MATRIX		GLASS CUTTER	BLACK MATRIX IS A THIN PATTERNED SILVER LAYER
2	GLASS CLEARING		ULTRASONIC BATH @ 40C	
3	COAT GLASS & BAKE WITH AN ALIGNMENT LAYER (PVA OR POLYIMIDE)	0.1	SPIN COATER & OVEN CURE	
4	ALIGN SURFACE LAYER		MANUAL BUFFING	
5	PET SUBSTRATE CUTTING, CLEAN & BUFF		CUTTER, ACETONE & BUFF CLOTH	
6	COAT CLC MIXTURE (LAYER #1) ON GLASS	10	KNIFE COATER @ 80C	REDUCE VISCOSITY BY HEATING VARIATION IN GLASS THICKNESS CAN AFFECT CLC THICKNESS
7	LAMINATE THE COATED GLASS SUBSTRATE TO PET		LAMINATOR @ 60C	
8	HEAT SAMPLE TO GENERATE 1ST COLOR		DIGITAL HOT PLATE	
9	MASK ALIGNMENT		MASK ALIGNER AND REFLECTIVE MICROSCOPE	
10	EXPOSE CLC TO UV THROUGH MASK		UV EXPOSURE SYSTEM	CROSSLINK CLC POLYMER AND POLYMERIZE 1ST COLOR
11	HEAT SAMPLE TO GENERATE 2ND COLOR		DIGITAL HOT PLATE	
12	EXPOSE CLC TO UV		UV EXPOSURE SYSTEM	CROSSLINK CLC POLYMER & POLYMERIZE 2ND COLOR (NO MASK NEEDED)

FIG. 9A

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STEP	PROCESS	TARGET THICKNESS ( $\mu\text{m}$ )	METHOD	COMMENTS
13	INTERLAYER BARRIER	1	DIP AND SPIN COAT	PREVENT DIFFUSION OF 1ST CLC LAYER INTO 2ND LAYER
14	CURE INTERLAYER BARRIER		UV EXPOSURE AND OVEN BAKE	
15	REPEAT STEPS 3 THRU 14 FOR 2ND CLC LAYER	11.1		IN THE FUTURE IT MAY BE POSSIBLE TO HAVE ONLY A SINGLE CLC LAYER
16	DEPOSIT GLUE LAYER	1	SPIN COAT	
17	TRANSFER 1/4 WAVE TO CLC STACK	5	PEEL 1/4 WAVE FILM OFF OF GLASS SUBSTRATE	1/4 WAVE IS FABRICATED ON A SEPARATE GLASS SUBSTRATE
18	CURE GLUE LAYER		UV & OVEN BAKE	
19	INTERLAYER BARRIER	1	DIP & SPIN COAT	PREVENT DAMAGE TO 1/4 WAVE FROM SOLVENTS IN PASSIVATION LAYER
20	COAT TOP PASSIVATION	2	SPIN COAT	TOP PASSIVATION SHOULD ALSO PROVIDE PLANARIZATION
21	CURE PASSIVATION		OVEN BAKE	
22	COAT ITO ON PASSIVATION		PVD SPUTTERING	
23	COAT POLYIMIDE LC ALIGNMENT LAYER		SPIN COAT & CURE (@ 230° FOR 1 HOUR)	
	TOTAL THICKNESS ( $\mu\text{m}$ )	31.2		WITH A SINGLE CLC LAYER THE THICKNESS CAN BE REDUCED TO $< 18 \mu\text{m}$ (SEE ATTACHED DRAWING)

FIG. 9B

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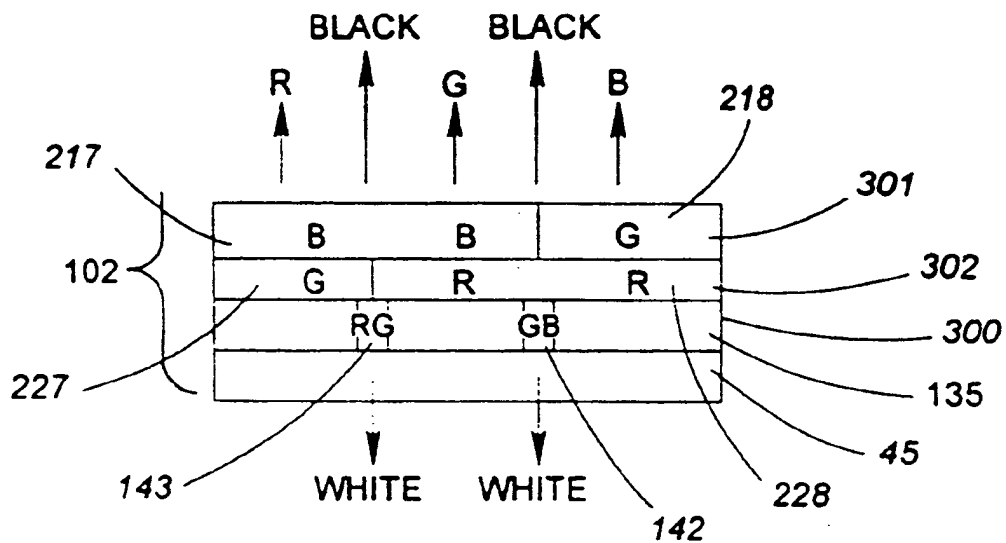


FIG. 10

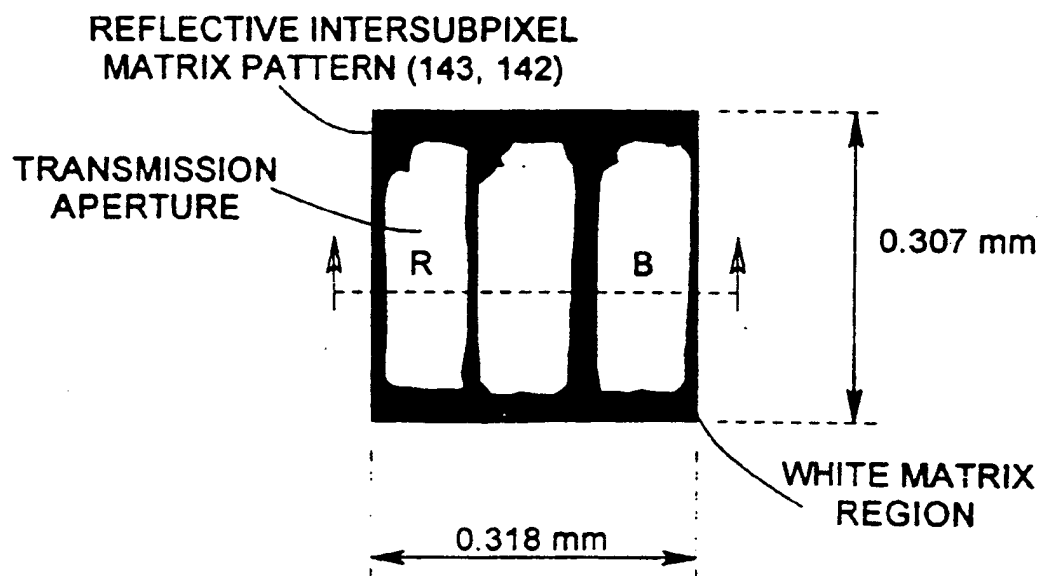


FIG. 10A



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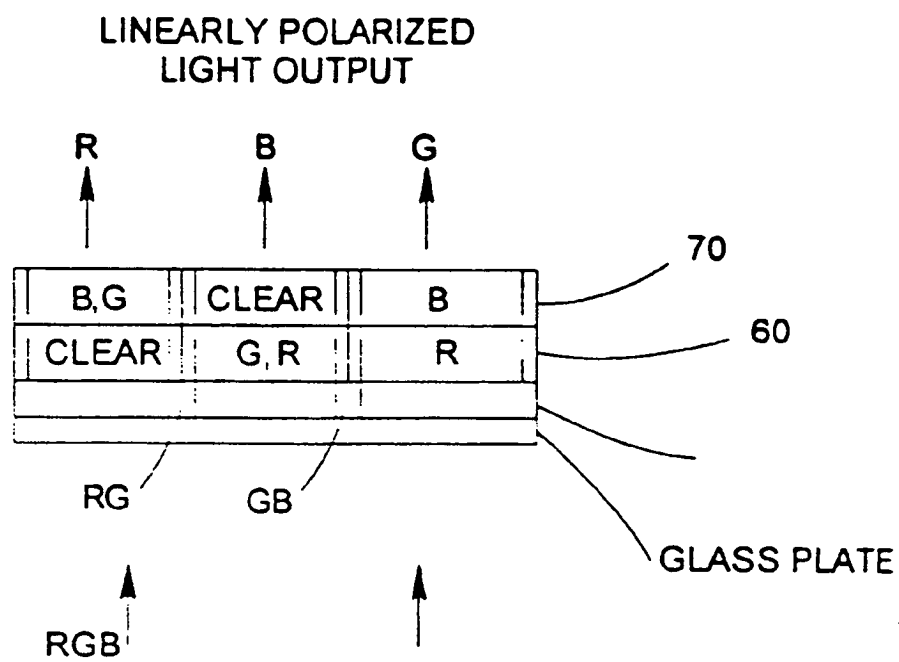


FIG. 11

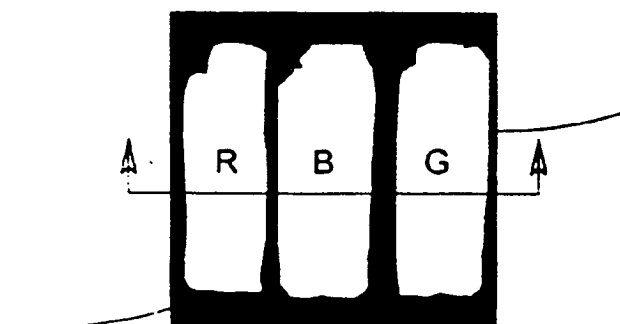


FIG. 11A

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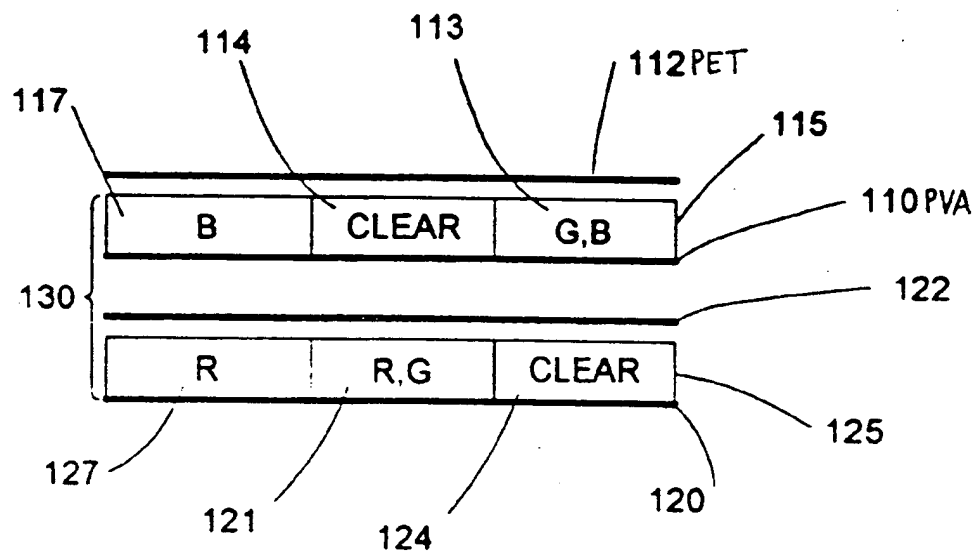


FIG. 12A

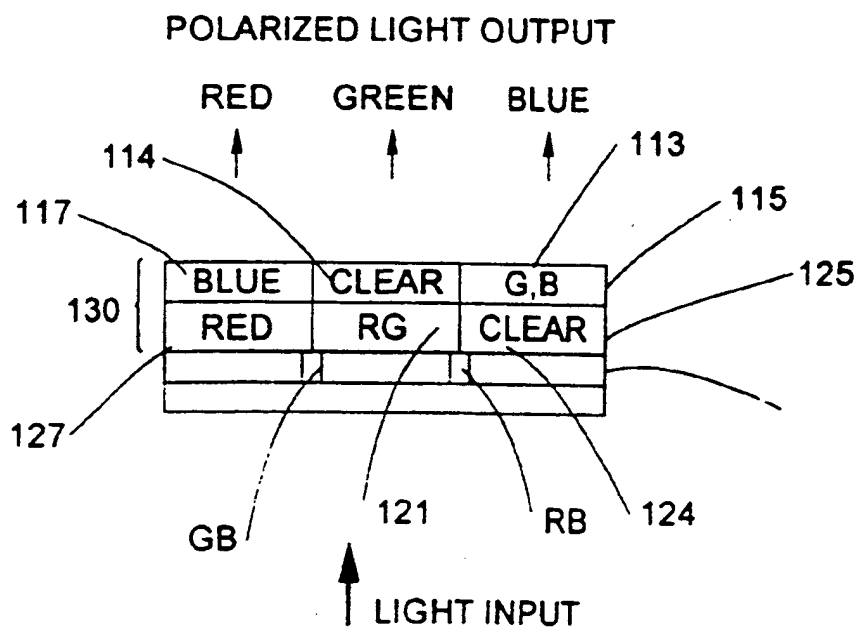


FIG. 12B

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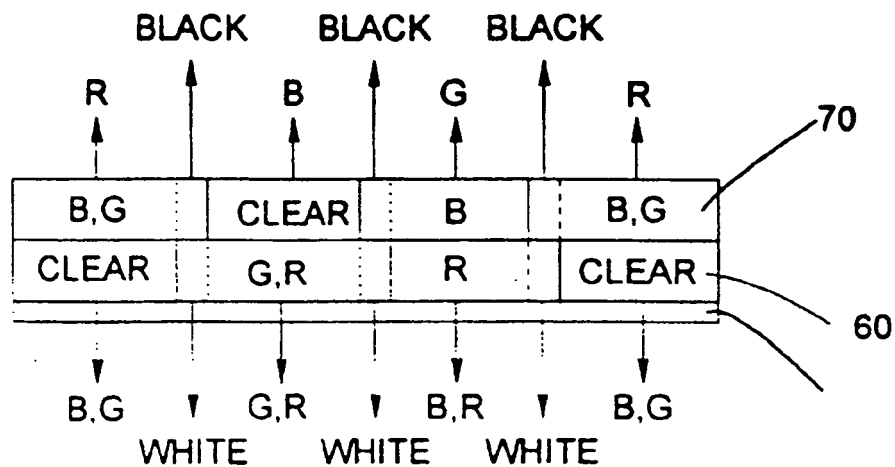


FIG. 13

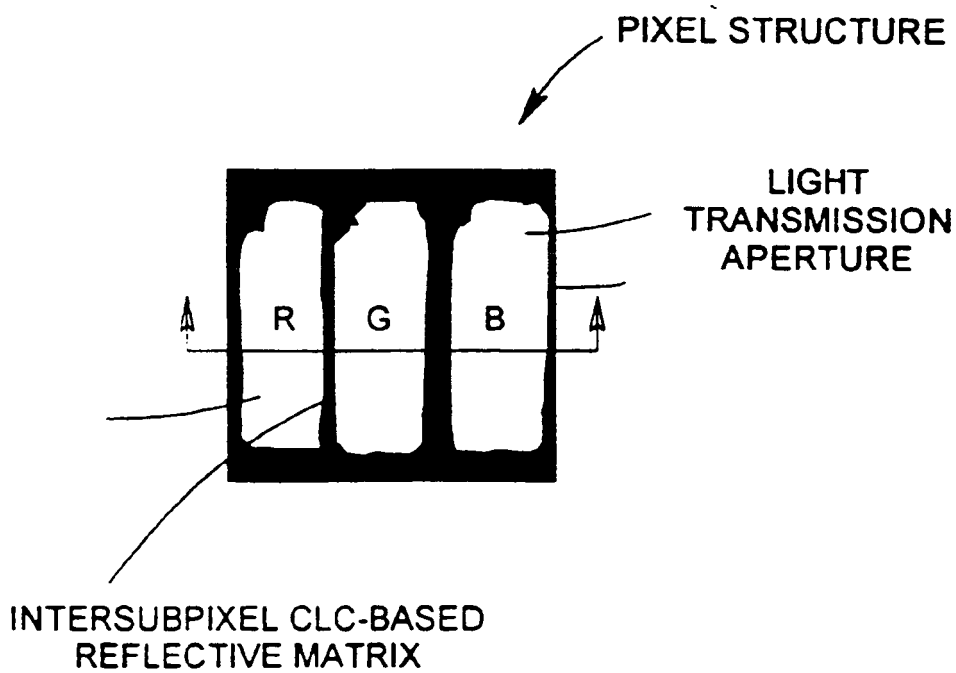


FIG. 13A

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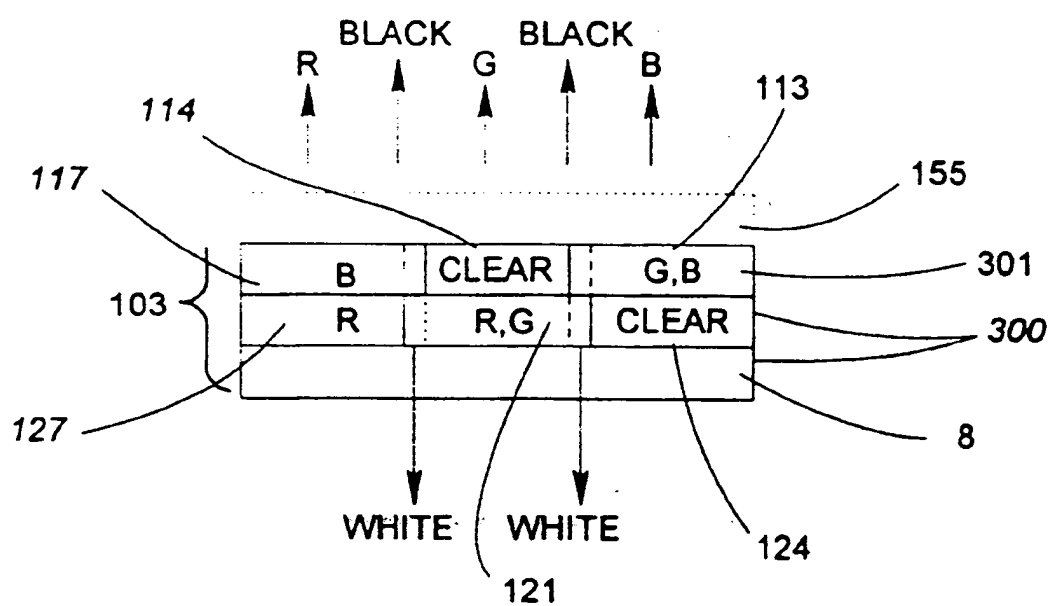


FIG. 14

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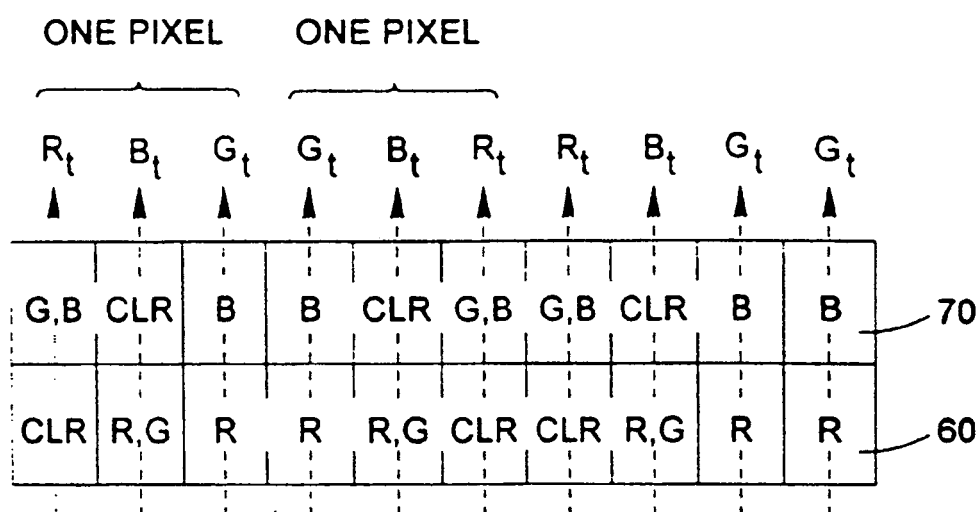


FIG. 15

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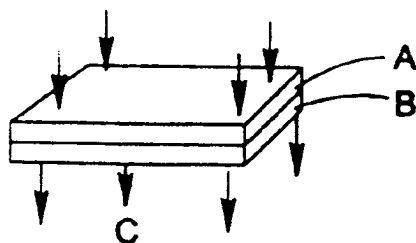


FIG. 16A

A

GB	B	GB	B
GR	CLR	GR	CLR
GB	B	GB	B
GR	CLR	GR	CLR

TOP LAYER

FIG. 16B

B

CLR	R	CLR	R
CLR	CLR	CLR	CLR
CLR	R	CLR	R
CLR	CLR	CLR	CLR

BOTTOM LAYER

FIG. 16C

R	G	R	G
B	CLR	B	CLR
R	G	R	G
B	CLR	B	CLR

TRANSMITTED PIXELS

FIG. 16D

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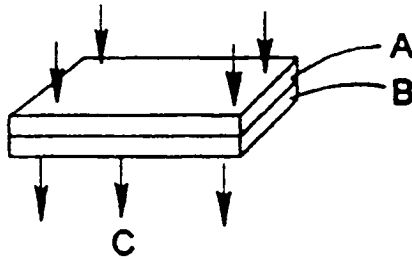


FIG. 17A

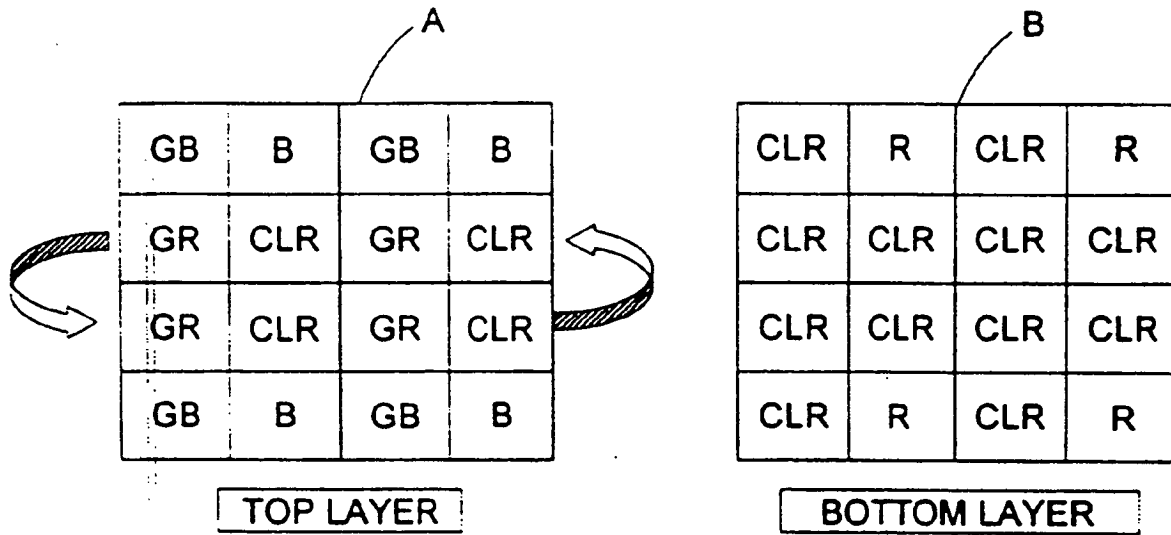


FIG. 17B

FIG. 17C

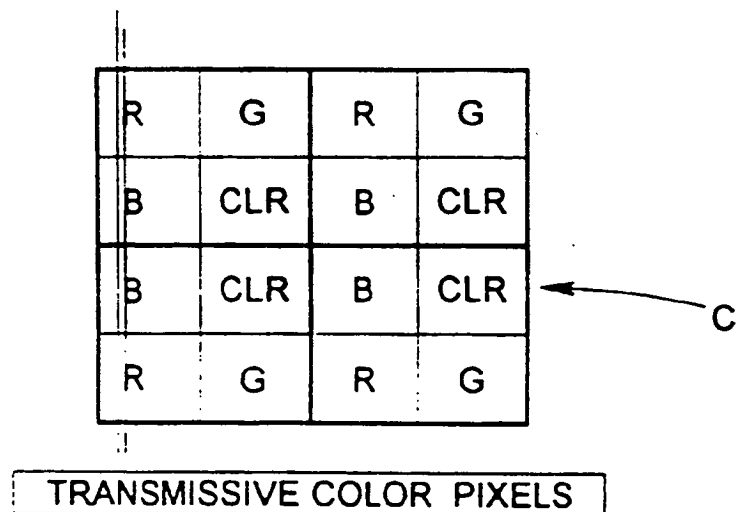


FIG. 17D

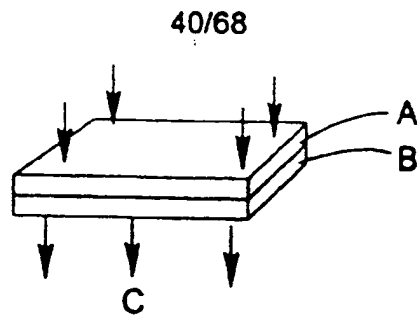


FIG. 18A

A

CLR	GR	GR	CLR
B	GB	GB	B
CLR	GR	GR	CLR
B	GB	GB	B

TOP LAYER

FIG. 18B

B

CLR	CLR	CLR	CLR
R	CLR	CLR	R
CLR	CLR	CLR	CLR
R	CLR	CLR	R

BOTTOM LAYER

FIG. 18C

CLR	B	B	CLR
G	R	R	G
CLR	B	B	CLR
G	R	R	G

C

TRANSMISSIVE COLOR PIXELS

FIG. 18D



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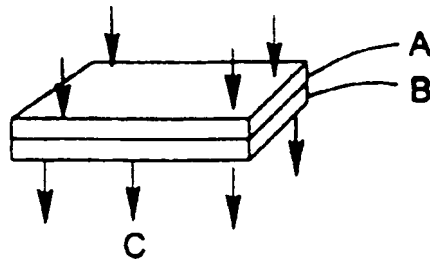


FIG. 19A

A

B	GB	GB	B
CLR	GR	GR	CLR
CLR	GR	GR	CLR
B	GB	GB	B

TOP LAYER

FIG. 19B

B

R	CLR	CLR	R
CLR	CLR	CLR	CLR
CLR	CLR	CLR	CLR
R	CLR	CLR	R

BOTTOM LAYER

FIG. 19C

G	R	R	G
CLR	B	B	CLR
CLR	B	B	CLR
G	R	R	G

TRANSMISSIVE COLOR PIXELS

FIG. 19D

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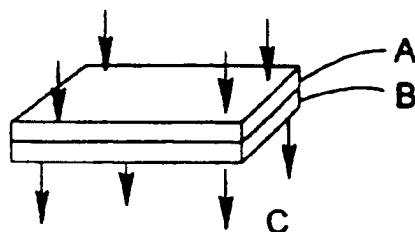


FIG. 20A

A

GR	CLR	GR	CLR
G	B	G	B
GR	CLR	GR	CLR
G	B	G	B

TOP LAYER

FIG. 20B

B

CLR	CLR	CLR	CLR
B	R	B	R
CLR	CLR	CLR	CLR
B	R	B	R

BOTTOM LAYER

FIG. 20C

B	CLR	B	CLR
R	G	R	G
B	CLR	B	CLR
R	G	R	G

C

TRANSMISSIVE COLOR PIXELS

FIG. 20D

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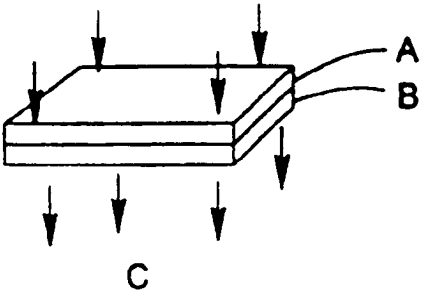


FIG. 21A

A

GR	CLR	GR	CLR
CLR	B	CLR	B
GR	CLR	GR	CLR
CLR	B	CLR	B

TOP LAYER

FIG. 21B

B

CLR	CLR	CLR	CLR
GB	R	GB	R
CLR	CLR	CLR	CLR
GB	R	GB	R

BOTTOM LAYER

FIG. 21C

B	CLR	B	CLR
R	G	R	G
B	CLR	B	CLR
R	G	R	G

TRANSMISSIVE COLOR PIXELS

FIG. 21D

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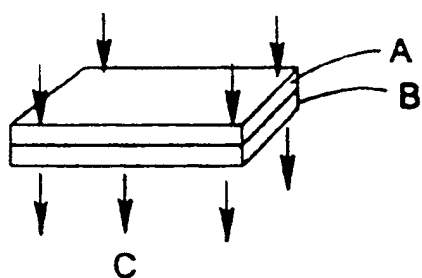


FIG. 22A

A

G	CLR	G	CLR
GB	B	GB	B
G	CLR	G	CLR
GB	B	GB	B

TOP LAYER

FIG. 22B

B

R	CLR	R	CLR
CLR	R	CLR	R
R	CLR	R	CLR
CLR	R	CLR	R

BOTTOM LAYER

FIG. 22C

B	CLR	B	CLR
R	G	R	G
B	CLR	B	CLR
R	G	R	G

C

TRANSMISSIVE COLOR PIXELS

FIG. 22D

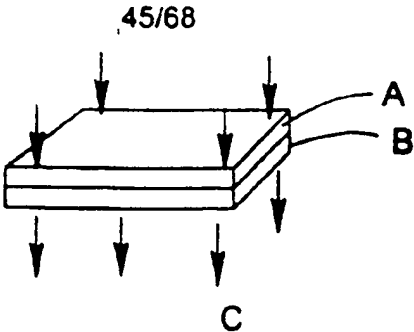


FIG. 23A

A

G	CLR	G	CLR
G	B	G	B
G	CLR	G	CLR
G	B	G	B

TOP LAYER

FIG. 23B

B

R	CLR	R	CLR
B	R	B	R
R	CLR	R	CLR
B	R	B	R

BOTTOM LAYER

FIG. 23C

B	CLR	B	CLR
R	G	R	G
B	CLR	B	CLR
R	G	R	G

C

TRANSMISSIVE COLOR PIXELS

FIG. 23D

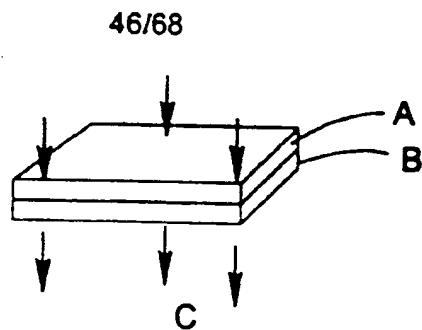


FIG. 24A

A

G	CLR	G	CLR
CLR	B	CLR	B
G	CLR	G	CLR
CLR	B	CLR	B

TOP LAYER

FIG. 24B

B

R	CLR	R	CLR
GB	R	GB	R
R	CLR	R	CLR
GB	R	GB	R

BOTTOM LAYER

FIG. 24C

	B	CLR	B	CLR
	R	G	R	G
	B	CLR	B	CLR
	R	G	R	G

C

TRANSMISSIVE COLOR PIXELS

FIG. 24D

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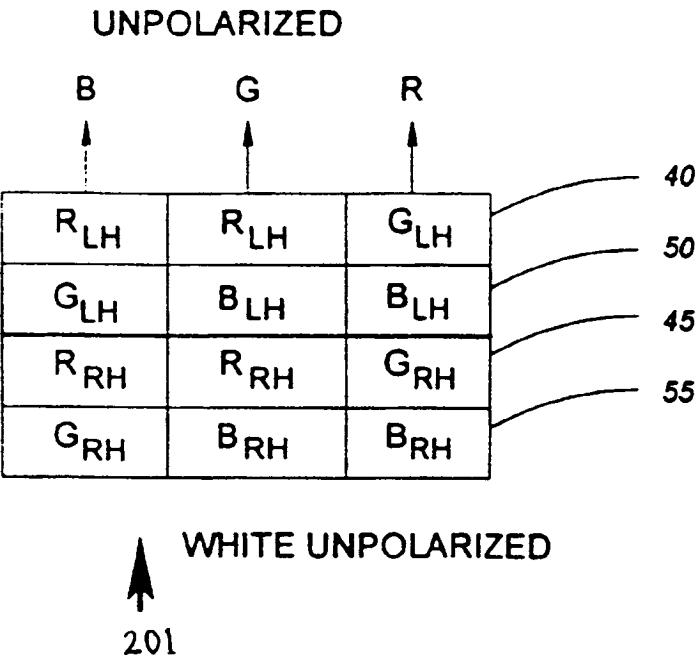


FIG. 25

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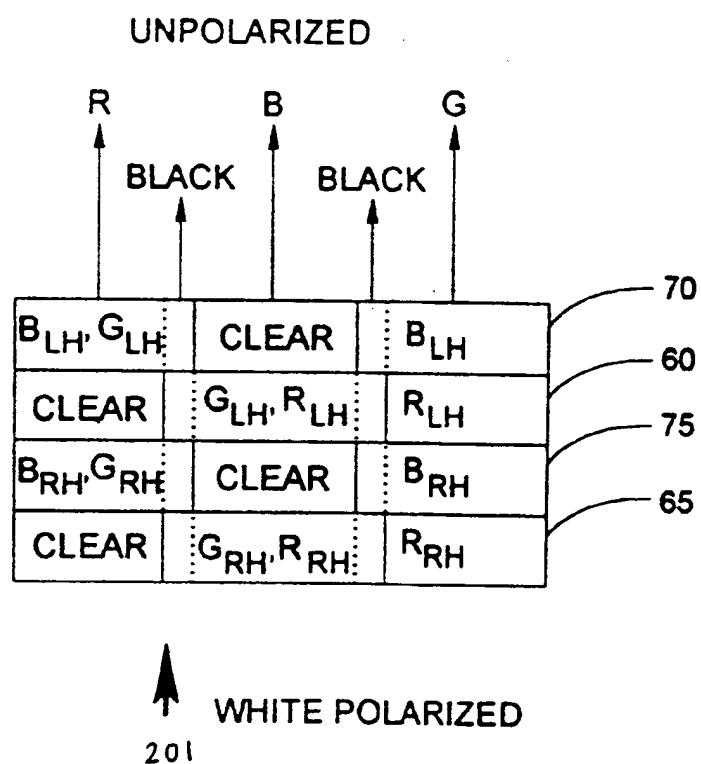


FIG. 26



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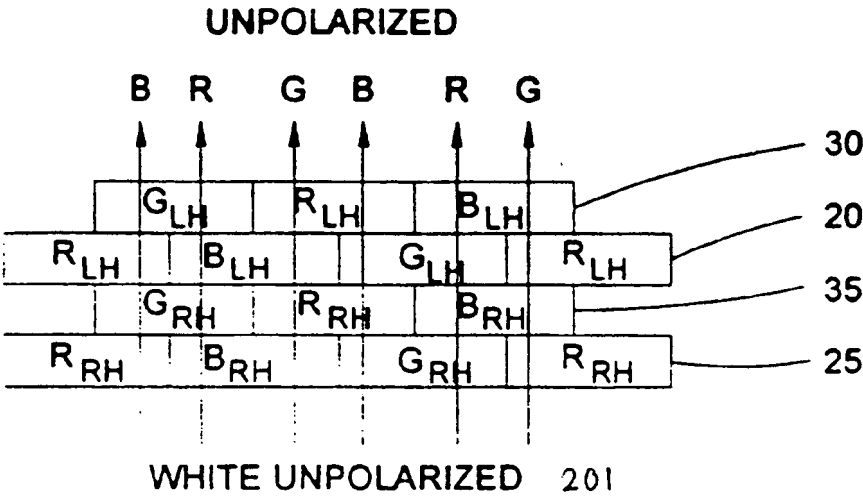


FIG. 27

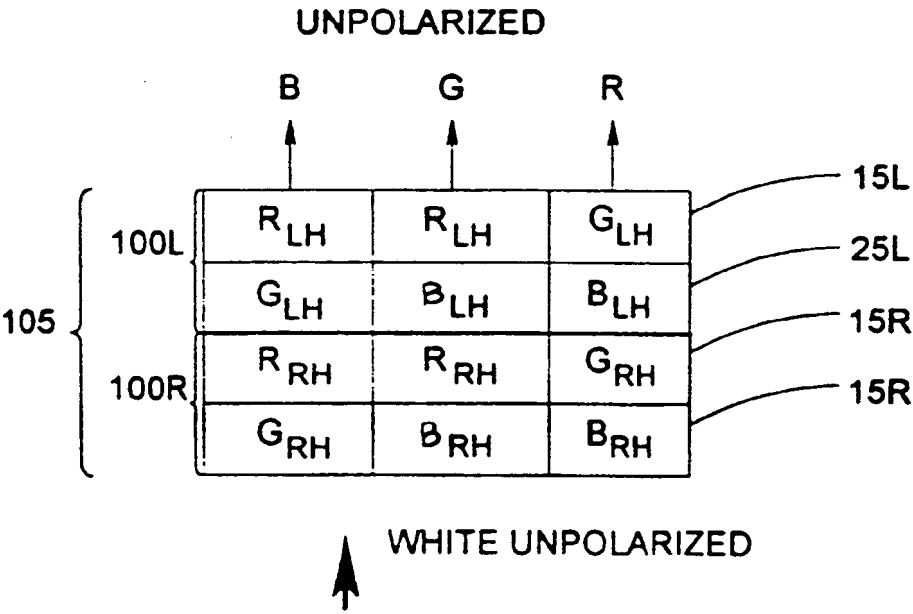


FIG. 28

# Super-Bright™ Color LCD

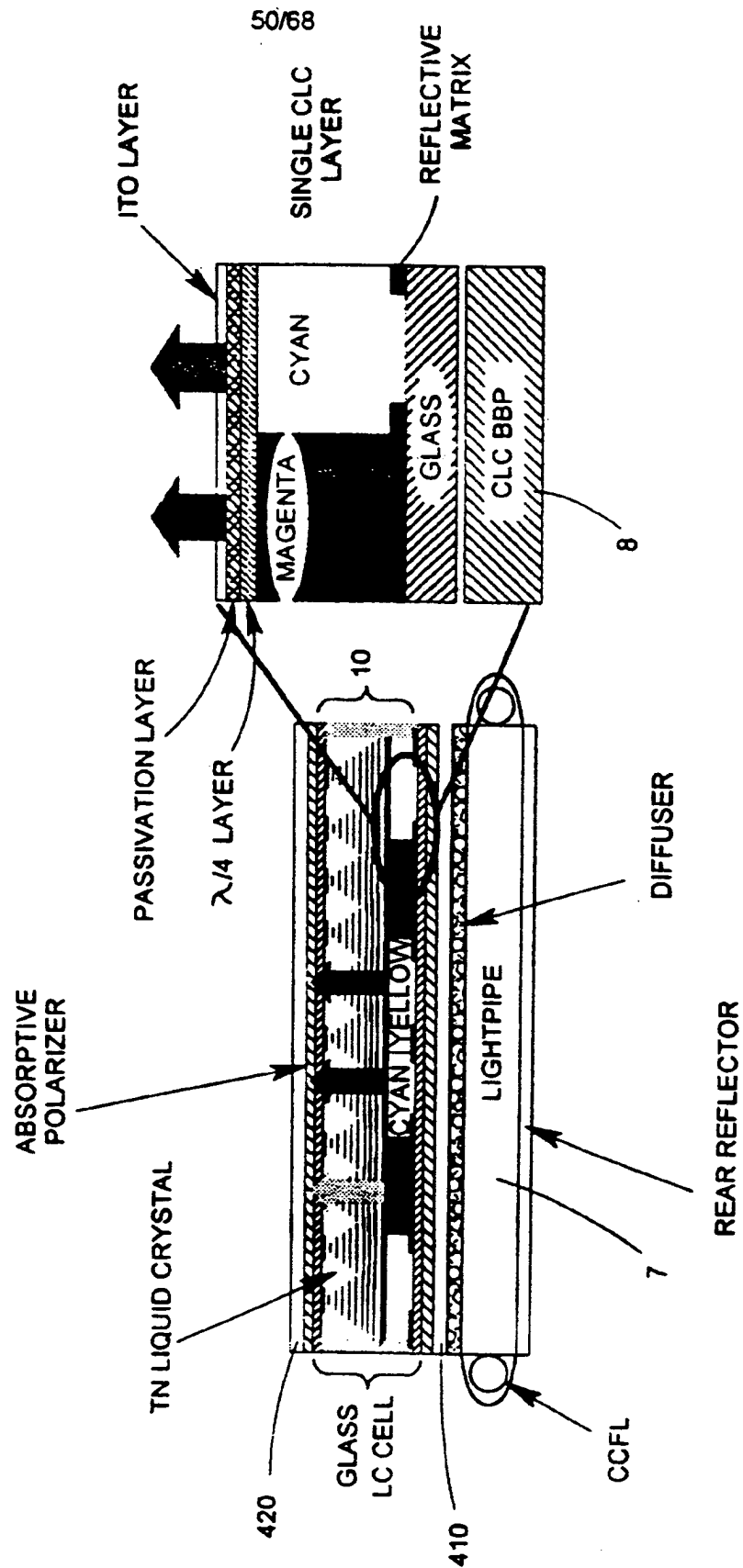


FIG. 29

# *Super-Bright™ Color Filters*

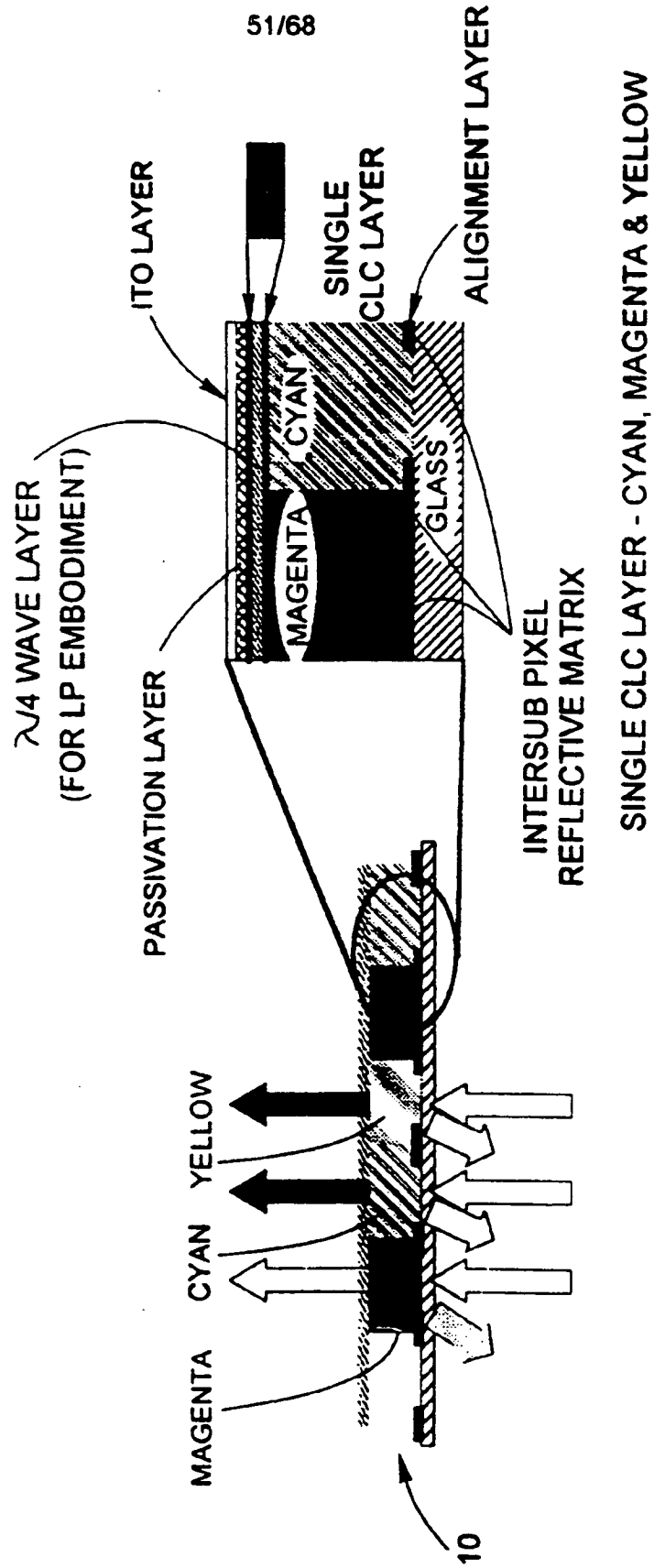
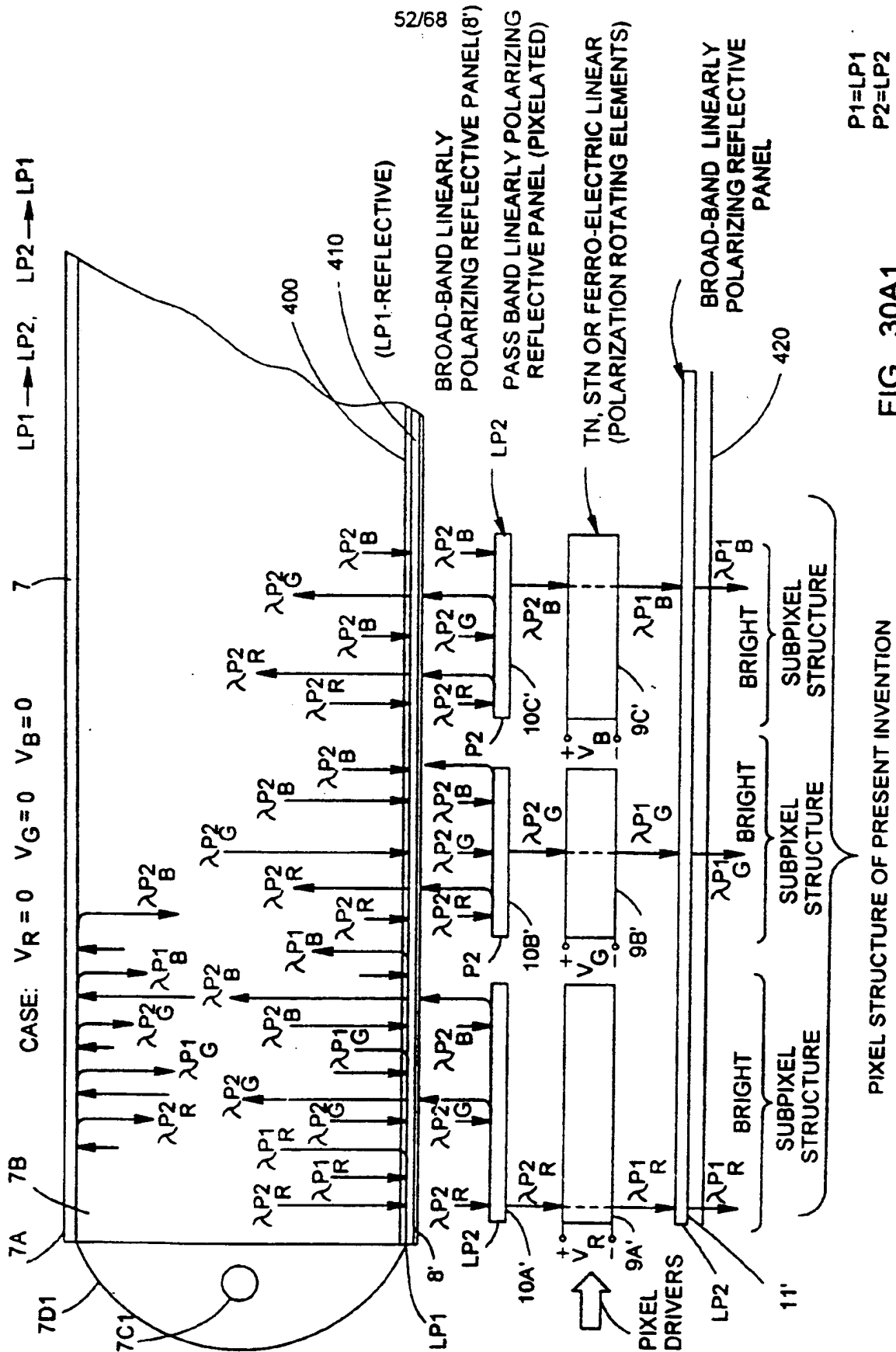


FIG. 29A

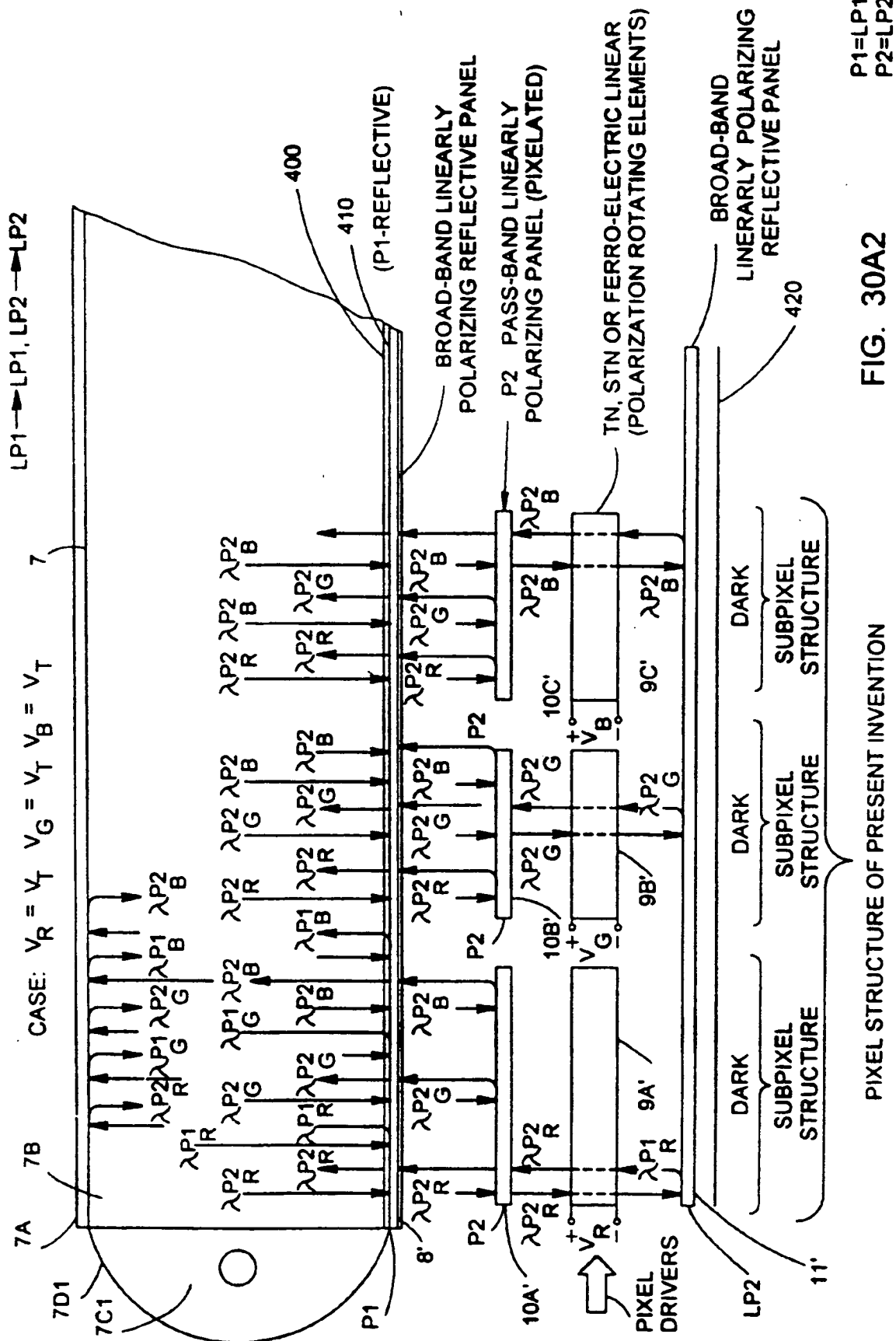


PIXEL STRUCTURE OF PRESENT INVENTION

FIG. 30A1

P1=LP1  
P2=LP2

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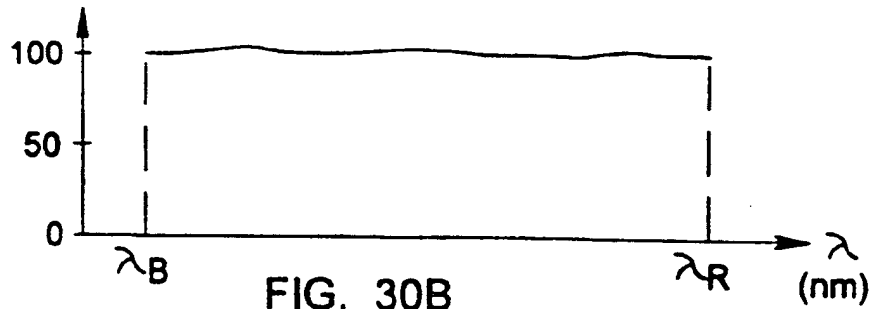
REFLECTION  
AT LP1  
%

FIG. 30B

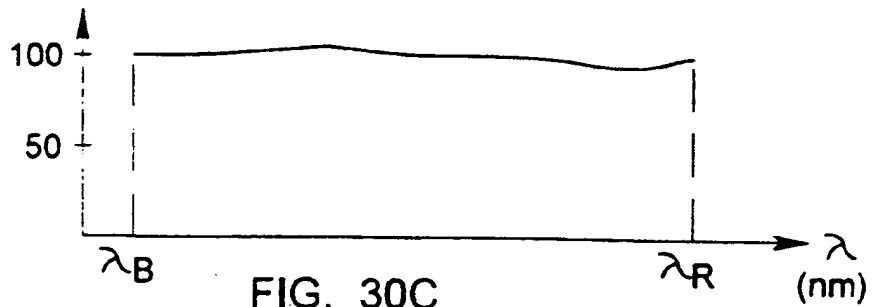
REFLECTION  
AT LP2  
%

FIG. 30C

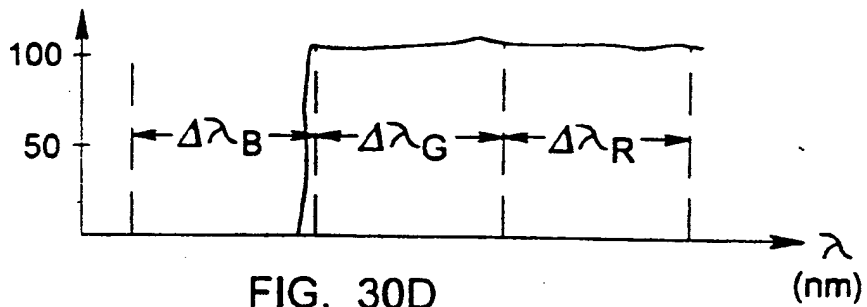
REFLECTION  
AT LP2  
%  
(BLUE)

FIG. 30D

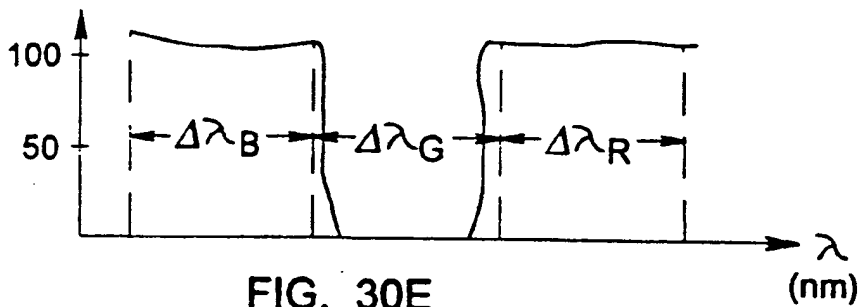
REFLECTION  
AT LP2  
%  
(GREEN)

FIG. 30E

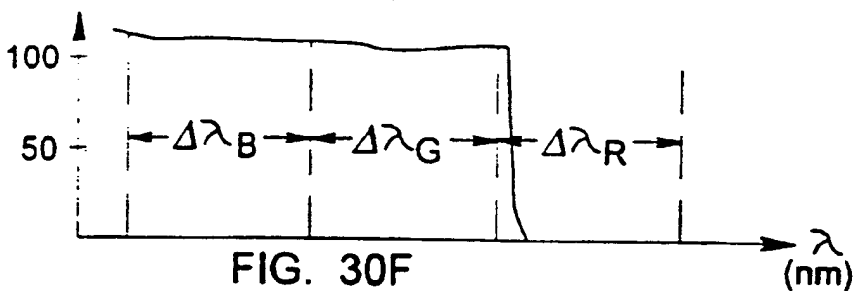
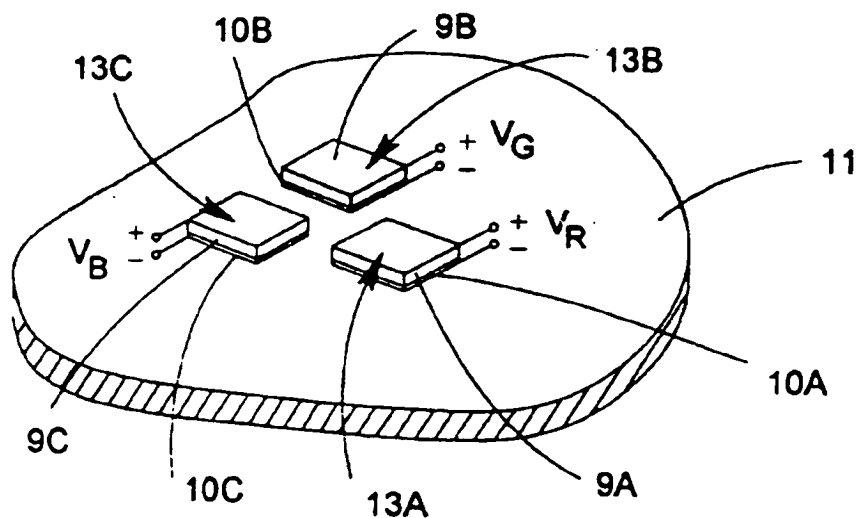
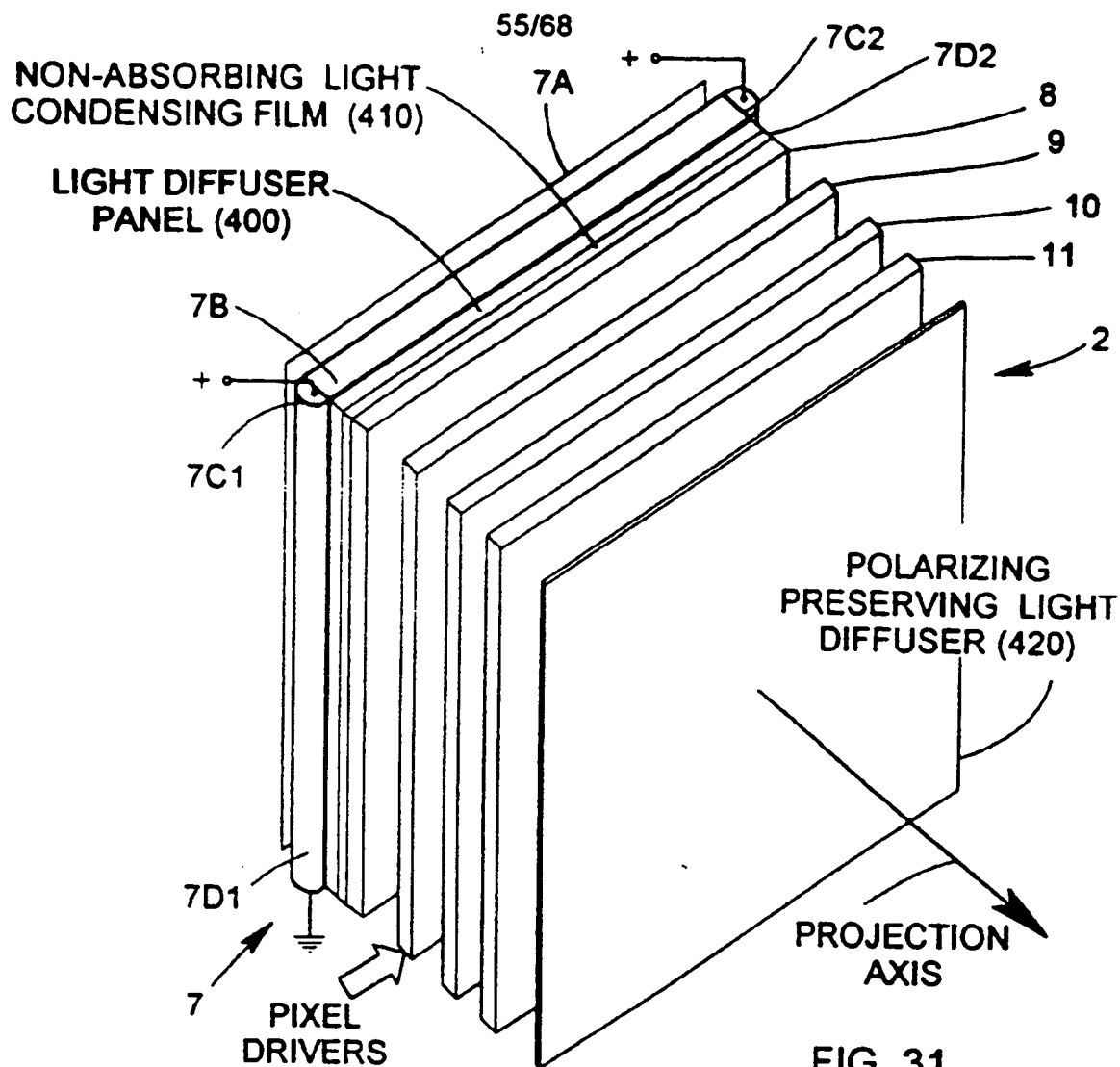
REFLECTION  
AT LP2  
%  
(RED)

FIG. 30F



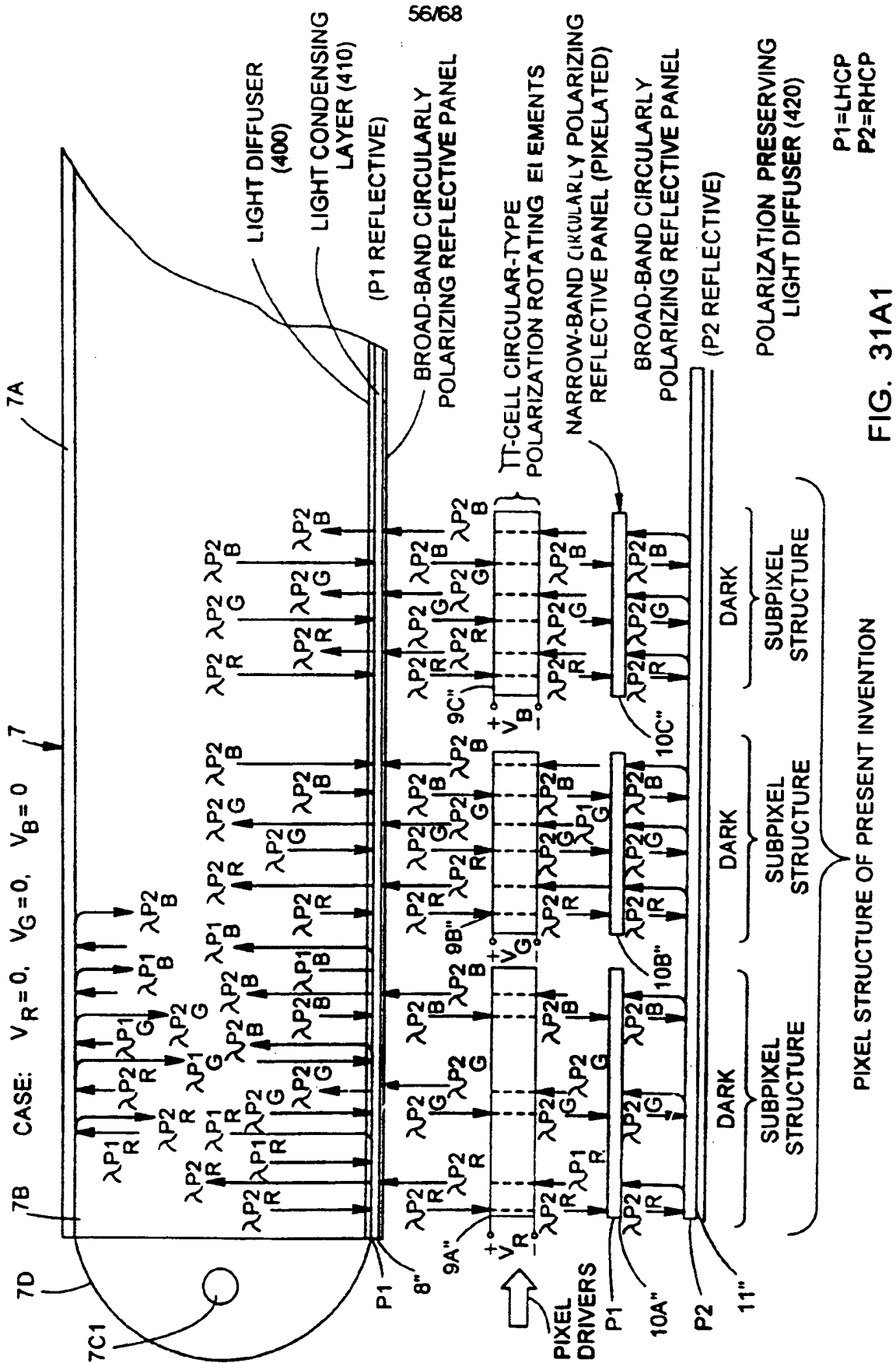
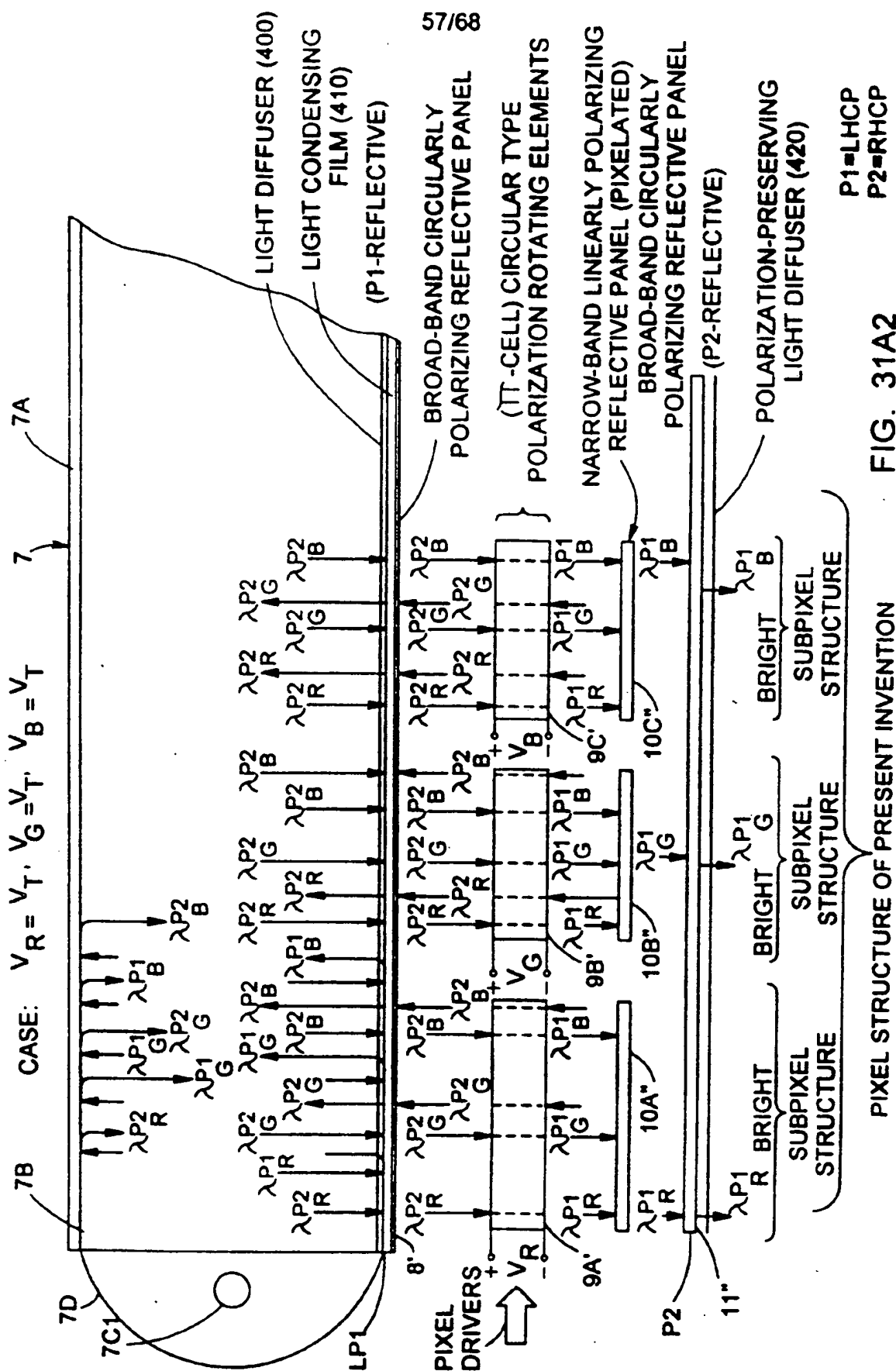


FIG. 31A1





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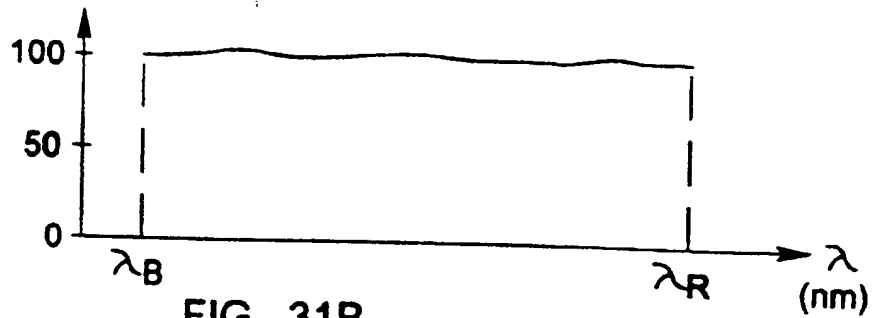
REFLECTION  
AT LHCP  
%

FIG. 31B

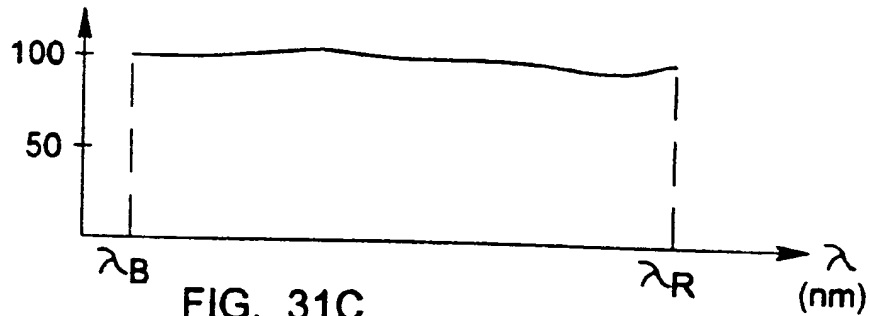
REFLECTION  
AT RHCP  
%

FIG. 31C

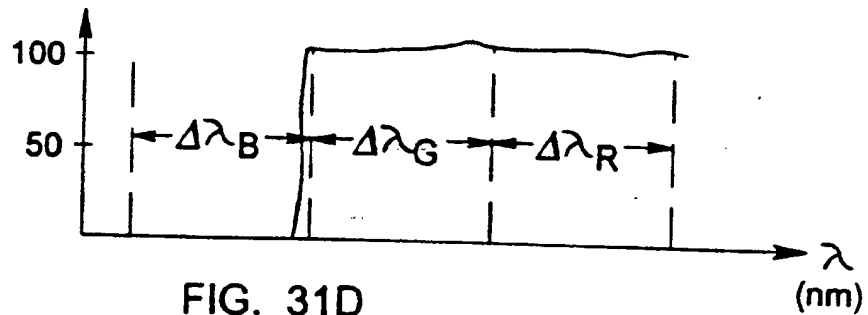
REFLECTION  
AT LHCP  
%  
(BLUE)

FIG. 31D

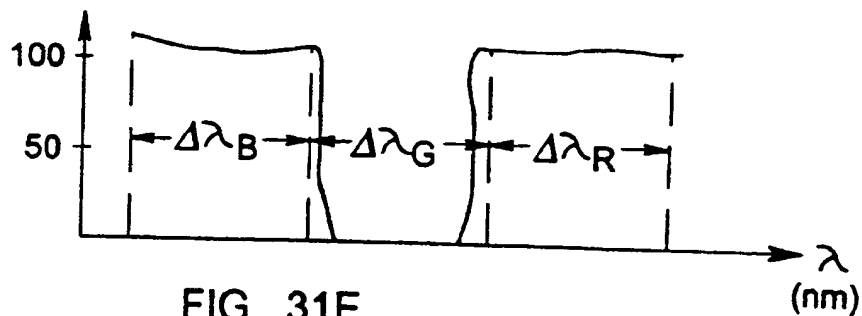
REFLECTION  
AT LHCP  
%  
(GREEN)

FIG. 31E

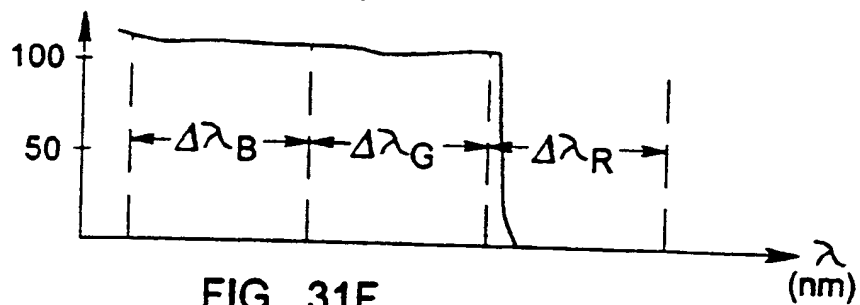
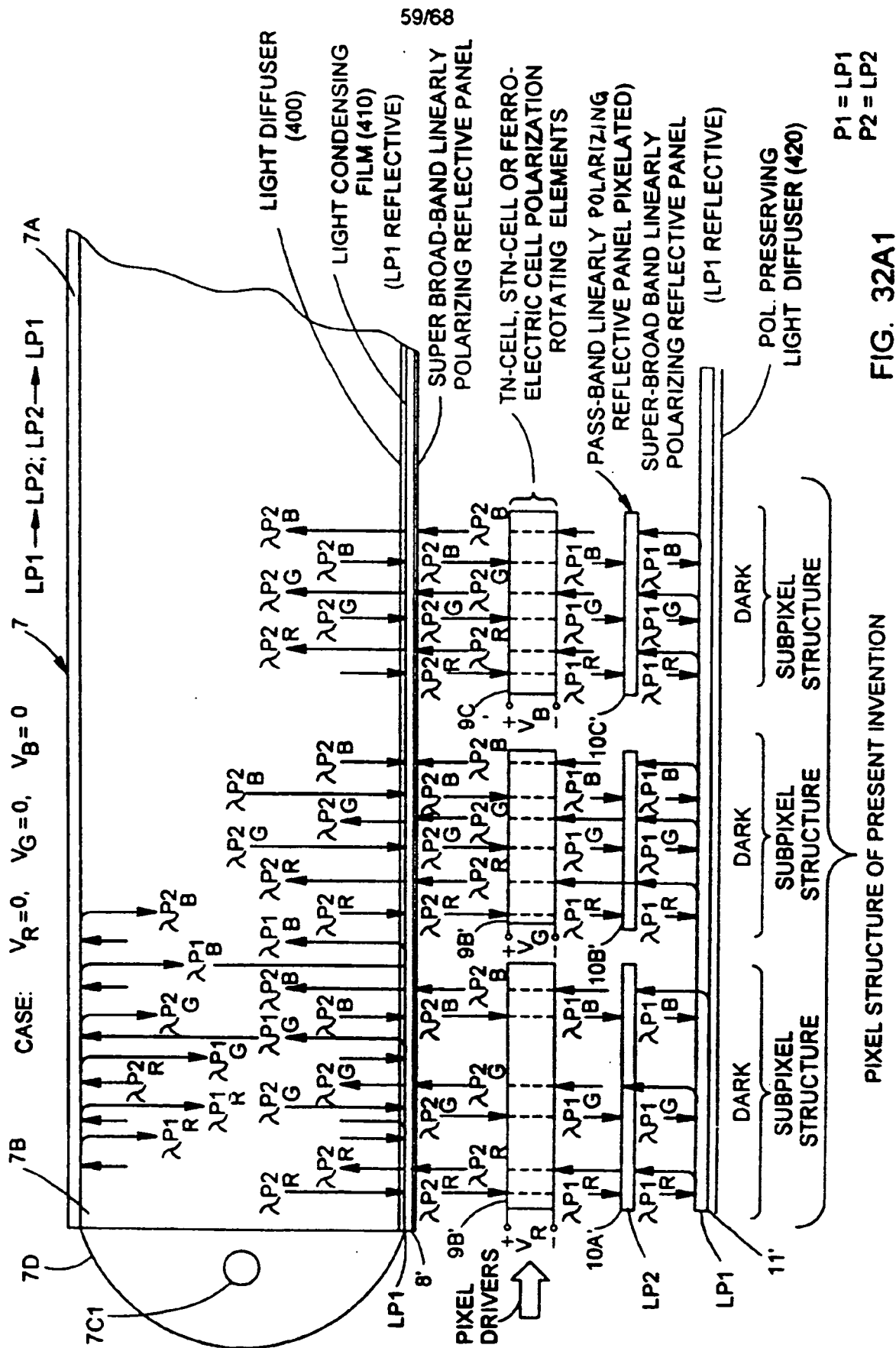
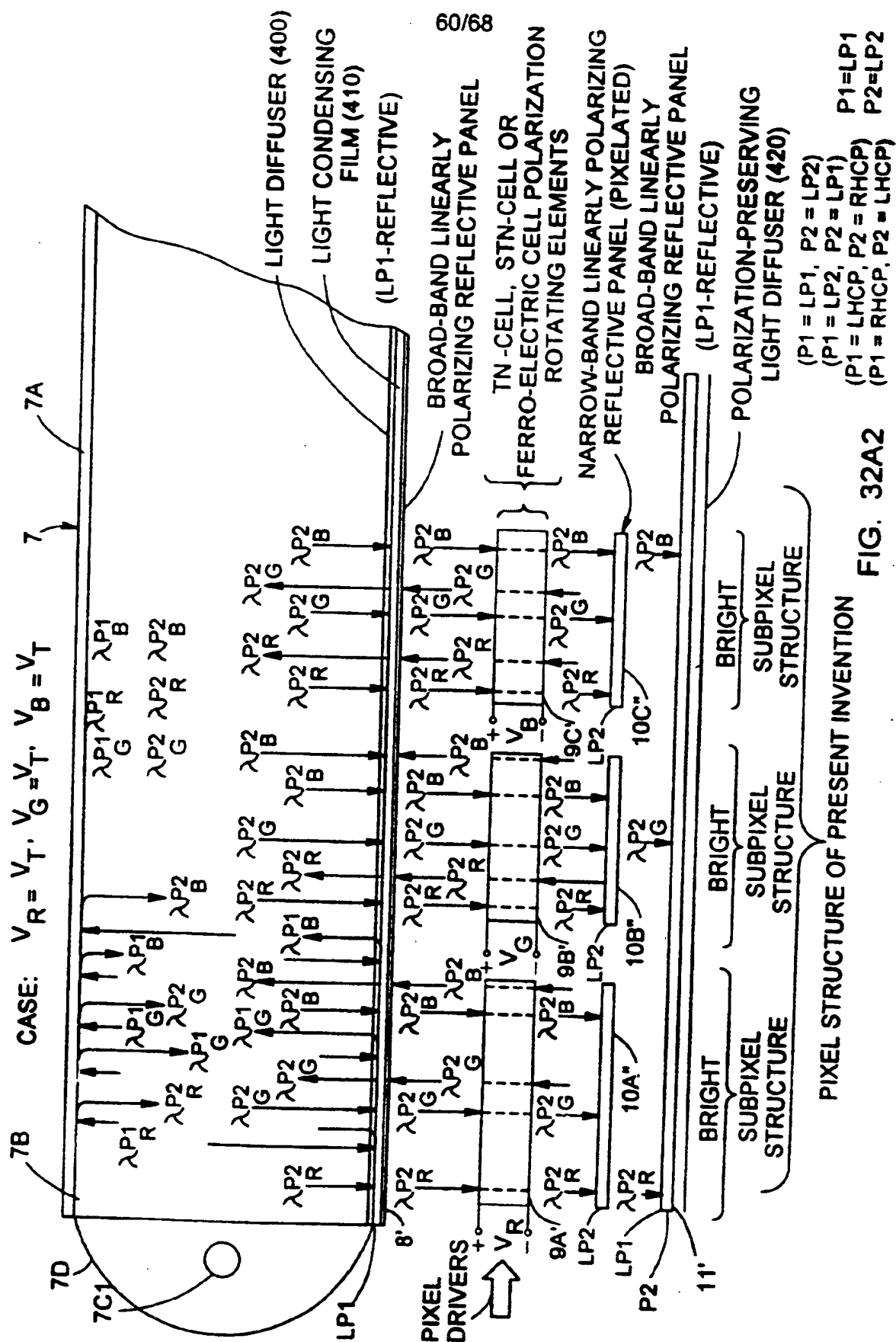
REFLECTION  
AT LHCP  
%  
(RED)

FIG. 31F





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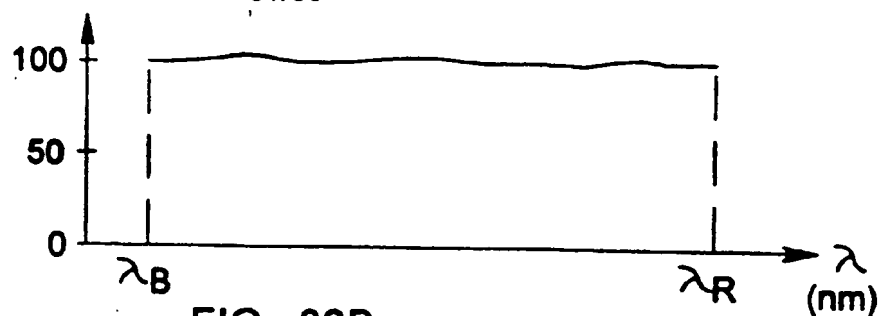
REFLECTION  
AT LP1  
%

FIG. 32B

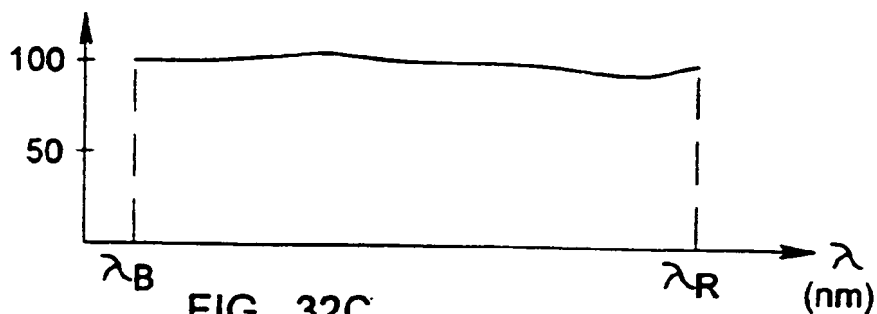
REFLECTION  
AT LP1  
%

FIG. 32C

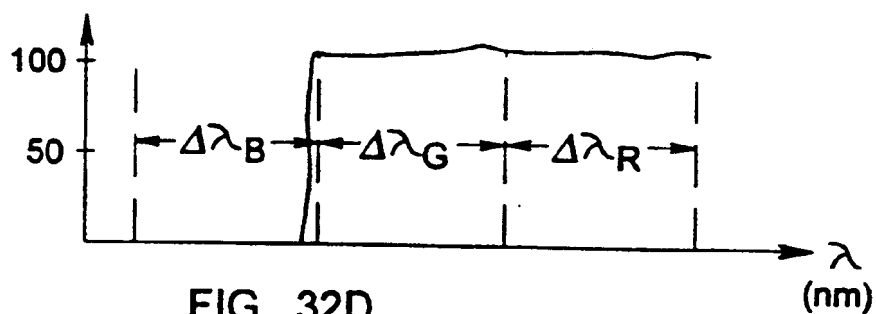
REFLECTION  
AT LP2  
%  
(BLUE)

FIG. 32D

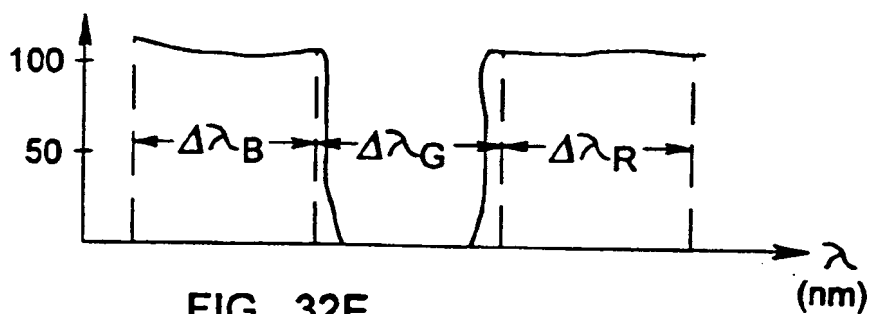
REFLECTION  
AT LP2  
%  
(GREEN)

FIG. 32E

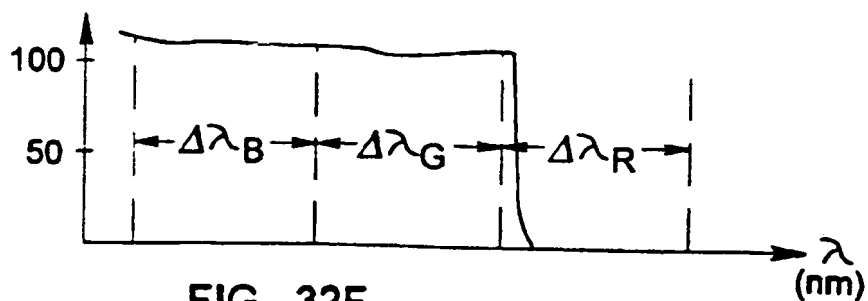
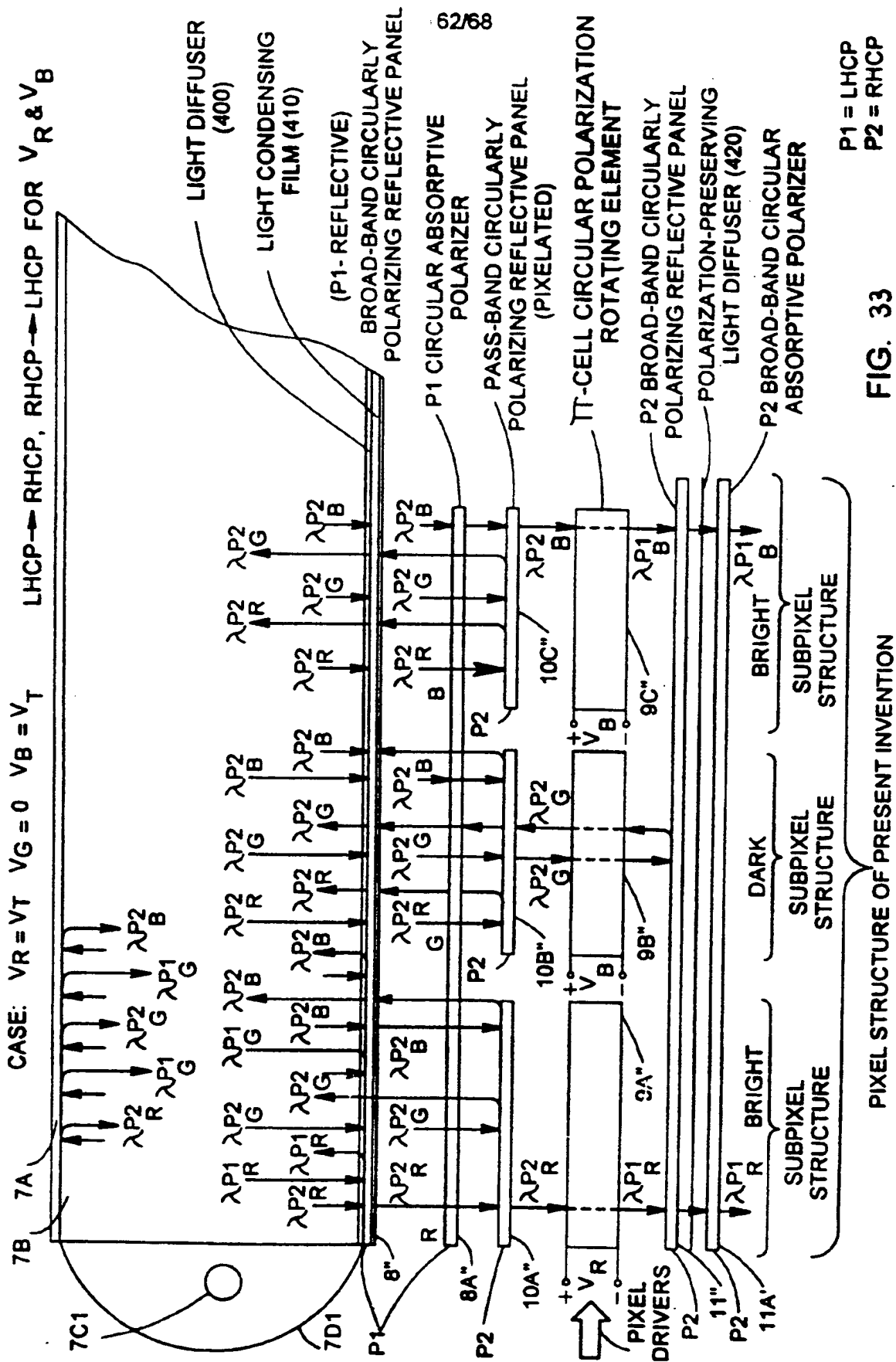
REFLECTION  
AT LP2  
%  
(RED)

FIG. 32F



PIXEL STRUCTURE OF PRESENT INVENTION

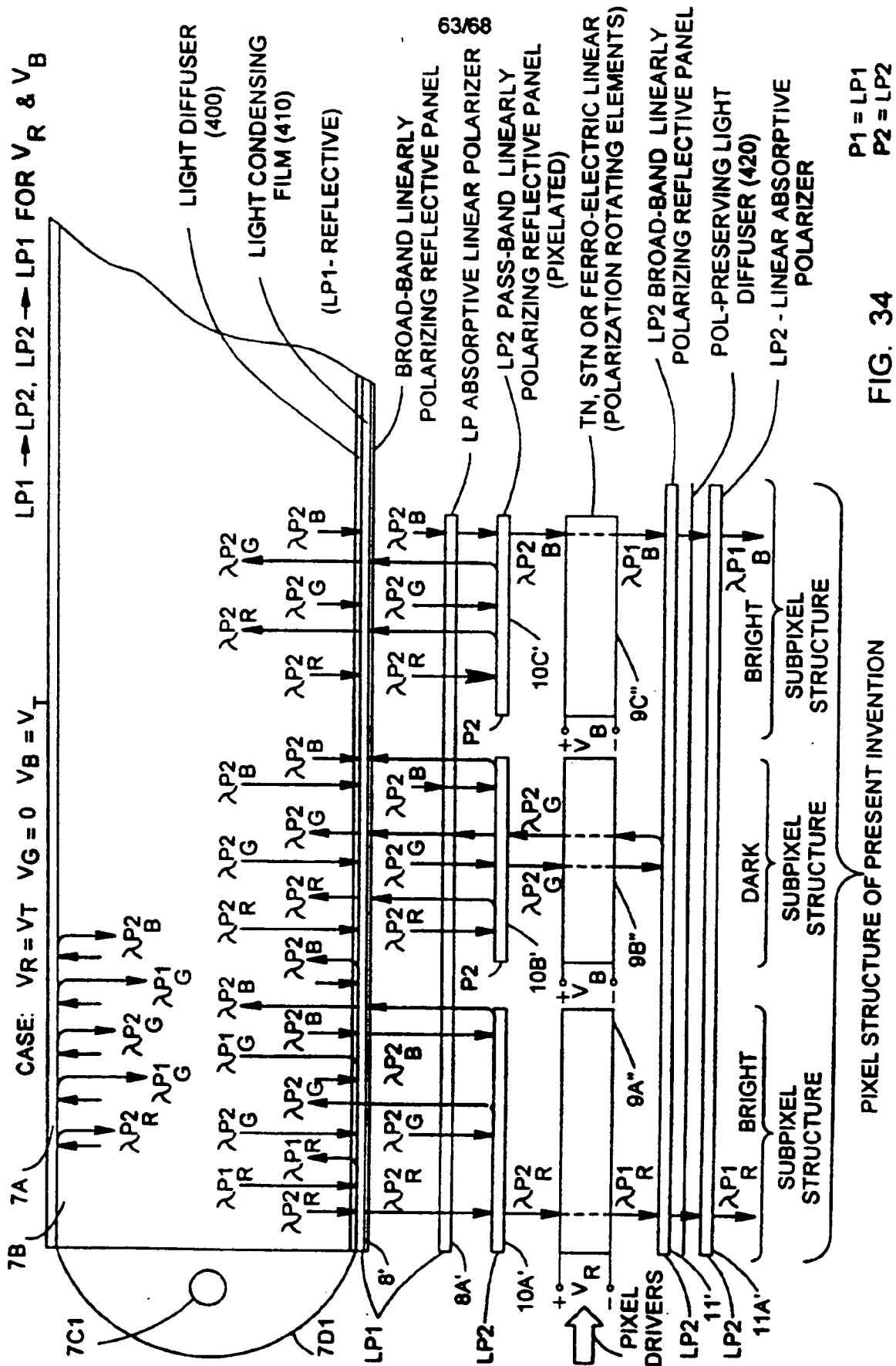
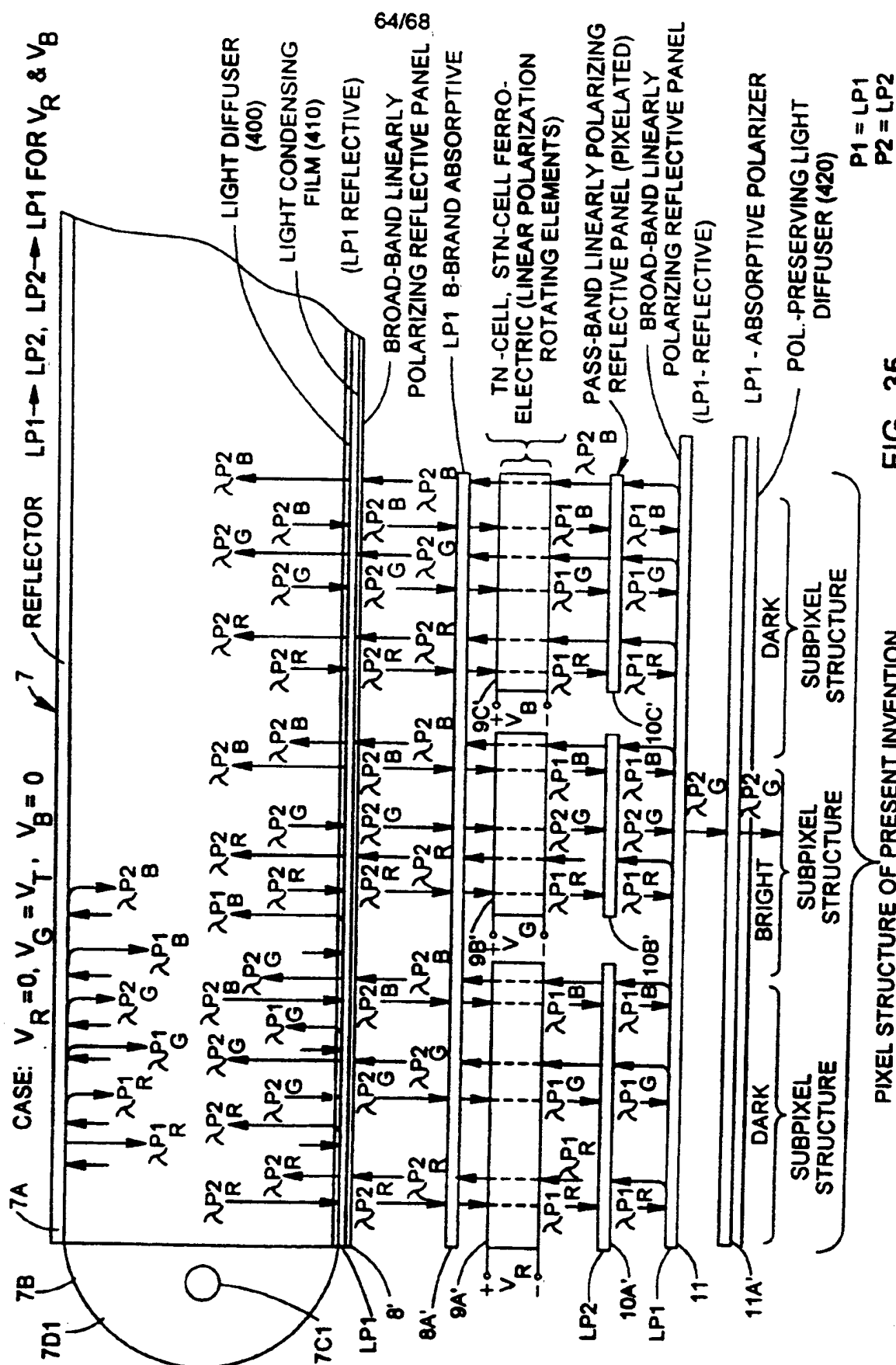
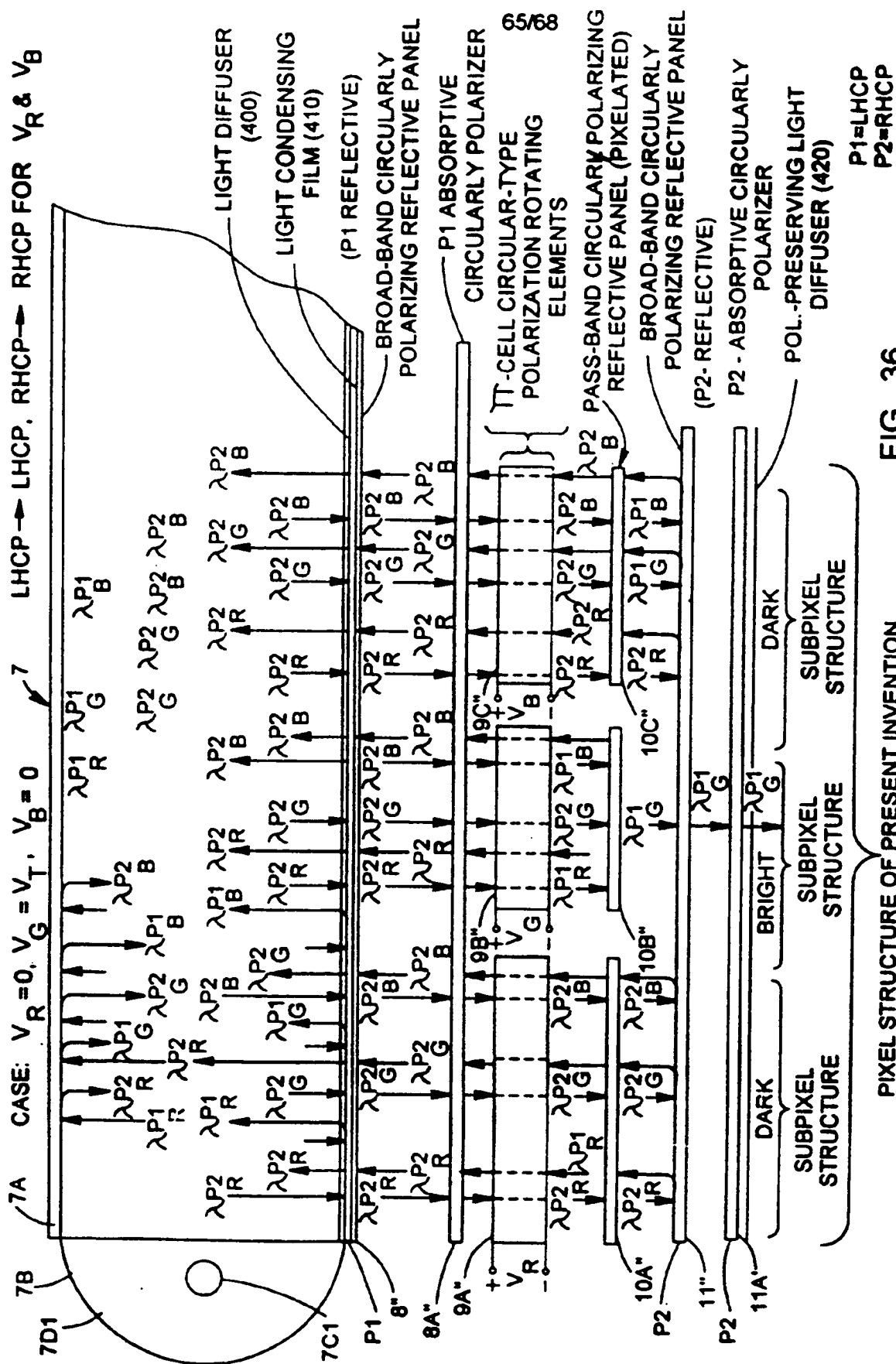


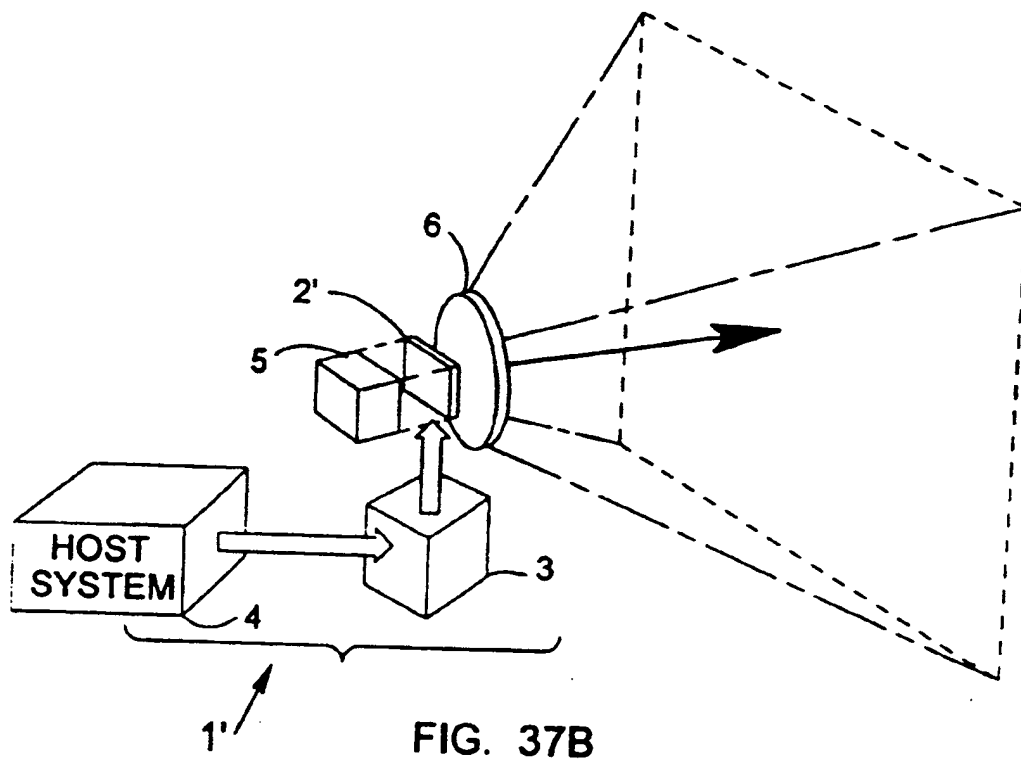
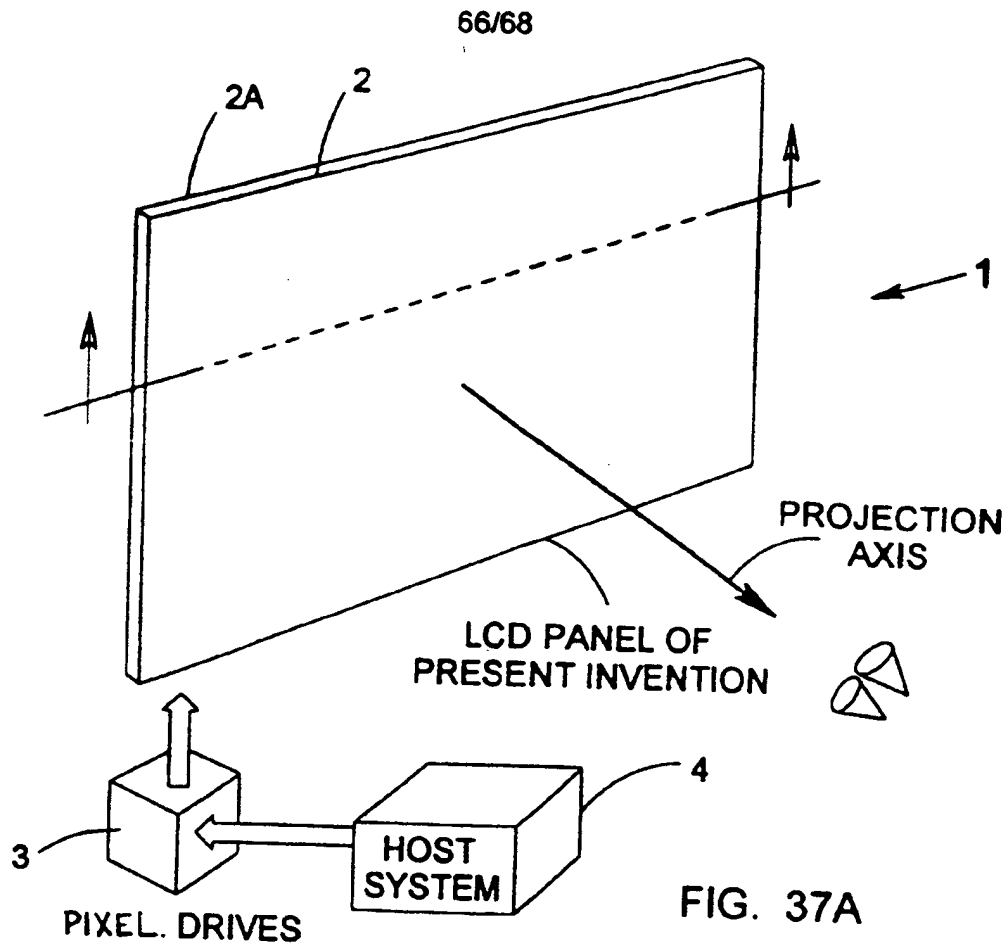
FIG. 34



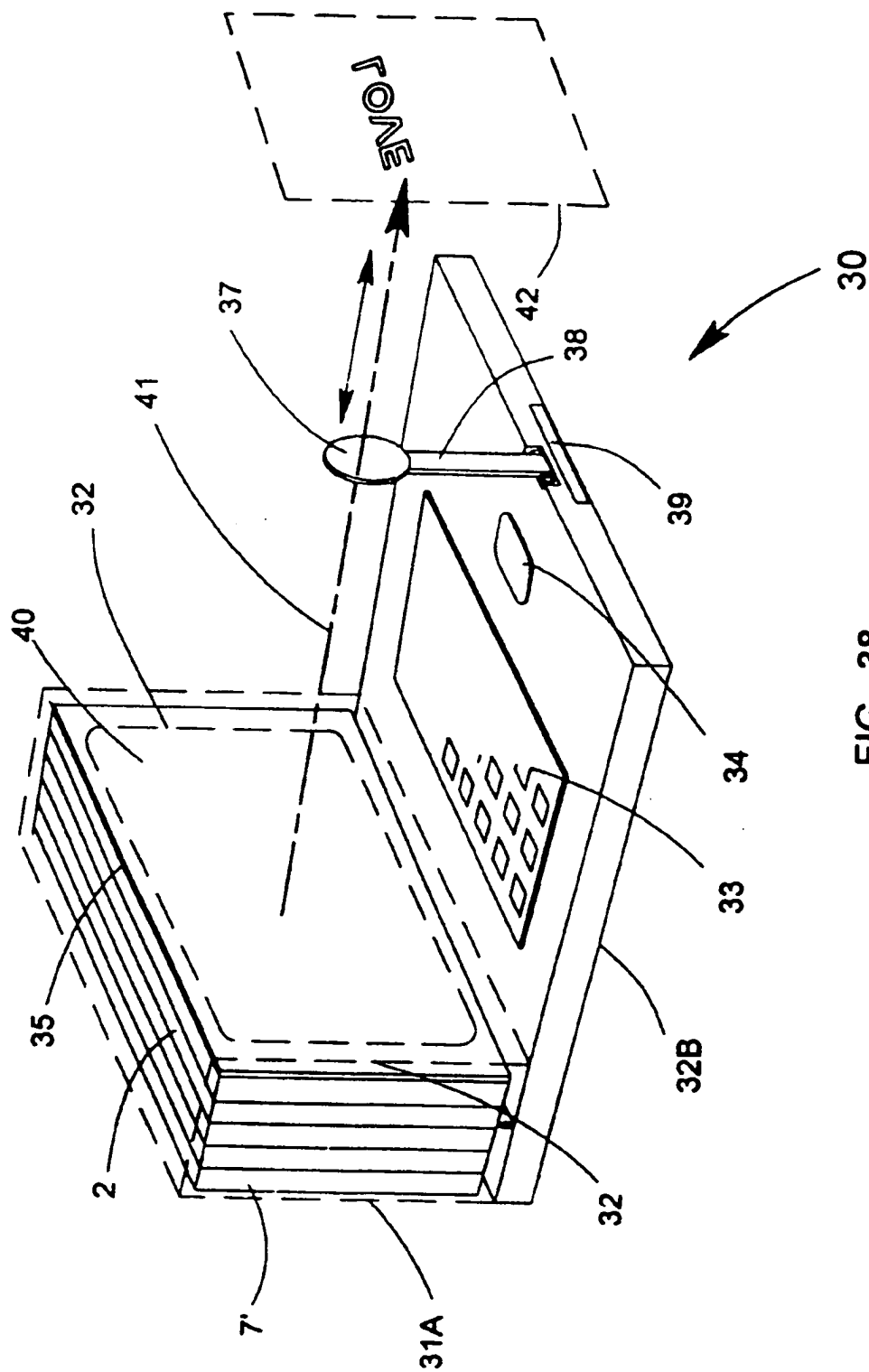
**FIG. 35**







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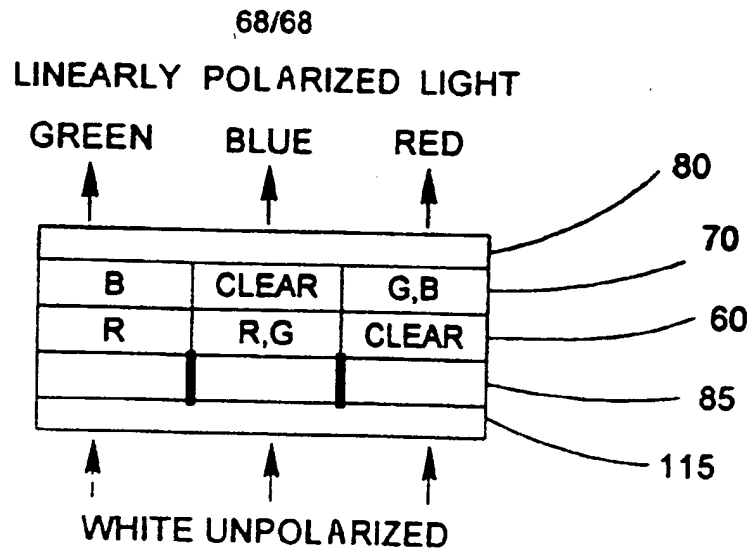


FIG. 39

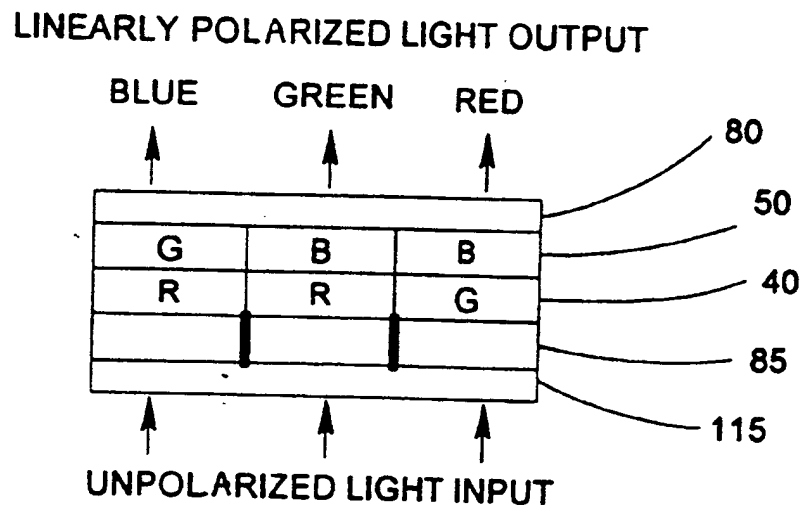


FIG. 40

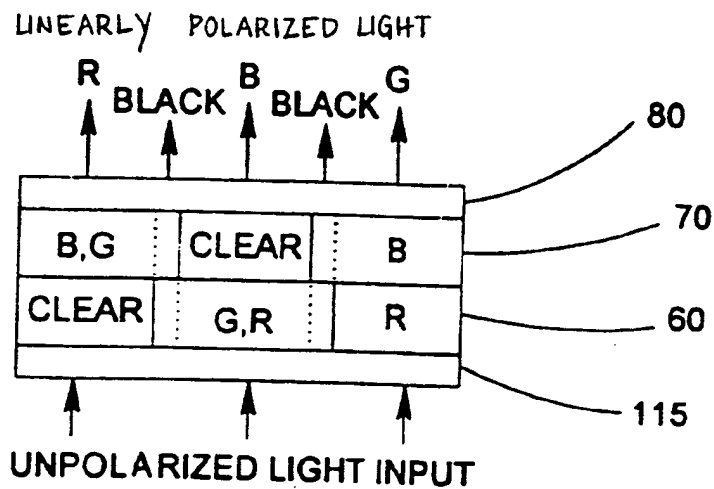


FIG. 41

## INTERNATIONAL SEARCH REPORT

International application No.  
PCT/US00/13562**A. CLASSIFICATION OF SUBJECT MATTER**

IPC(7) : G02F 1/1335

US CL : 349/096, 106, 115

According to International Patent Classification (IPC) or to both national classification and IPC

**B. FIELDS SEARCHED**

Minimum documentation searched (classification system followed by classification symbols)

U.S. : 349/096, 106, 115

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

NONE

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)

EAST

**C. DOCUMENTS CONSIDERED TO BE RELEVANT**

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
A	US 5,822,029 A (Davis et al) 13 October 1998 (13.10.1998), figure 2	1-172

☐

Further documents are listed in the continuation of Box C.

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See patent family annex.

## \* Special categories of cited documents:

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"&amp;"

document member of the same patent family

Date of the actual completion of the international search

20 JULY 2000

Date of mailing of the international search report

14 AUG 2000

Name and mailing address of the ISA/US  
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